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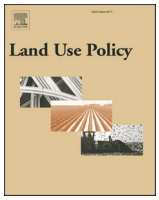

Meta-analysis of land use systems development in Africa: Trajectories, implications, adaptive capacity, and future dynamics

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ABSTRACT

In the face of a multiplicity of crises – including land cover change, climate hazards, economic uncertainties, social injustice, adaptation and sustainability concerns, relevant stakeholders have taken stern initiatives to avert these phenomena that continuously grow in magnitude and relevance. We investigate the driving mechanisms of land use cover change, across Africa's sub-regions using integrated remote sensing techniques and existing literature. Modules for Land Use Change Evaluation (MOLUSCE) and ANN-CA were utilized to simulate land use scenarios (2020–2050) in Africa. Fundamental drift in land use systems was found to be driven by an array of socio-political, economic and biophysical factors. Interestingly, *land use and recover change (LURC)* patterns were observed in the north and west African regions. A regrowth/greening in forests (+2.67 %) and a decline in deserts/barren areas (-16.62 %), grasslands (-16.58 %) and farmlands/shrubs (-12.88 %) can be observed during the last 40 years. Conversely, massive shifts in built-up (+216.52 %) and areas covered by waterbodies (+84.44 %) can be spotted. Predicted trends for natural vegetation estimate 1.69 % and 2.92 % reduction rates annually for forests and grasslands, respectively, over the next 30 years. The piecemeal of evidence provided shows more lands will be converted into built-environment and cultivated lands. Based on these premises, we propose a *'4R value strategy'* that unifies actions, addresses resource-related conflicts and the drivers identified, amid sustainability concerns. The study's standpoints prompt the decisions of governments, the scientific community and interested parties to create alternative futures by tackling prevailing trends which aggravate environmental degradation and poverty.

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1. Introduction

Populations worldwide are increasingly living in cities, resulting in increased human activities such as concrete construction, industrialization, and land reclamation that affect natural resources (Bai et al., 2017). Lately, cities are continuously expanding, leaving less area for other land-use systems such as forestry, agricultural, and natural habitats. This can have devastating consequences on the environment, impacting wildlife habitats, biodiversity, and climate. Global deforestation has been on the rise since the 20th century, with estimates suggesting that around 15 billion trees are being destroyed each year (IPCC, 2022; UN-Habitat, 2019). This is largely due to logging, agricultural expansion, and urbanization. Understanding land cover change (LCC) over time is a primary facet of Land Use Systems Development (LUSD) analysis. From 1973–2013, it is estimated that agricultural land accounts for the largest increase in global land-use, growing from 15 % to 33 % (IPCC, 2022). Forests, on the other hand, have dropped from 31 % to 23 % over the same period. Furthermore, grasslands, wetlands, and others have declined significantly as well. This shift in land cover is expected to continue, with projections that suggest further increases in croplands while the area of forests, rangelands, and wetlands continues to decline.

Presently, regional and local issues are prioritized when making land use decisions (Chigbu, 2022). For example, local governments are now more prone to considering their environment to accommodate their population's various needs, allowing for better coordination between their own Land Use Systems (LUS) and those of nearby regions. New insights based on several reports and scholarly standpoints have revealed that data-driven decision making is paramount when it comes to managing land use systems at different levels. The increasing sophistication of satellite technology and digital mapping services has aided the ability to track land use changes and make informed decisions (Aboelnour and Engel, 2018). By utilizing such technologies, governments and corporations alike can begin to better understand the size, strength and even social demography of different regions (Gong et al., 2013).

1.1. Urban-rural land linkages: classical and contemporary context

According to Mullin (1967), Archer (1983) and Becker (2008), the evolution of the keywords "rural" and "urban" is predated and linked to the classical Latin terms "*rus (open space)*" and "*urbs (city).*" Country sides or open spaces were classified as *rus*, whereas cities or large towns with territorial and exclusive boundaries were designated as *urbs*. In reality or everyday life, these two terms co-exist and are driven by the "*push or pull theory.*" However, frustrations have been expressed concerning the contentious growths that distinguish the *rus* and the *urbs*. Historical narratives from existing literature like that of the Roman poet, Quintus Horatius Flaccus, in his poems, frequently expressed the desire to overcome "the divorce between countryside and city (Archer, 1983: 160 and 181; Mullin, 1967)." This, however, substantiates the link and discourse between both terms, having pre-existed since time immemorial. Despite the long history of disparities in development between rural and urban areas, the dynamics of land tenure and imbalance in spatial planning and development linger to leave both areas to be developed in unequal ways. Contemporarily, attempts (constituting policies, plans, programs and projects (PPPPs)) to leverage or ensure both areas have equal attention have been prioritized on different fronts by different states, scientific and international organizations. This global discourse for development has drawn engagements from different disciplines, sectors, schools of thought, and political interests. In realizing this from a sectoral perspective, the International Federation of Surveyors, FIG, attempted to establish the relevance and linkages between urban and rural areas for sustainable development. These steps were initiated through the Marrakech Declaration, which sought to sensitize relevant stakeholders on all fronts, and for two decades down memory lane, issues that border urban and rural areas (Fig. 1), which are embodiments of LUSD, still remain with us. A surge in recent literature (Chigbu, 2021; Chigbu et al., 2021) and guiding principles developed by FIG and UN-Habitat through the Global Land Tool Network (GLTN) outline some actions in response to issues surrounding this subject. Our study contributes to emerging frontiers by proposing a construct '4R value strategy' within the context of sustainable development and transformative governance for alternative futures, and lasting land-use governance in Africa.

Fig. 1 presents the bottlenecks faced by each spatial zone in LUSD. LUSD is driven by land tenure structures, exclusive rights, space utilization and the general interests of individuals, governments and organizations. Chigbu (2022) opines that the interrelationship between these parameters influences the movement of goods and services, individuals, information and knowledge. Through an urban-rural networking model, Chigbu (2022) highlighted four critical encompassing factors that anchor such interactions; *Consumption* (i.e., utilization of land, forest and water resources, food systems and so on), *Exchanges* (i.e., transport, mobility, culture, accessibility, distribution and marketing), *Governance* (i.e., decisions and institutional policies, governance systems, development and planning), and *partnerships* (spatial interactions resulting in the evolution of functional spaces). It further highlights the over-lapse and encompassing nature of challenges in tri-spatial worlds, thus, rural, urban and peri-urban areas. These interactions and responses (Fig. 1) drive land use systems development. Within the context of Africa and its sub-regions, a comprehensive study that clearly investigates the core and potential drivers of land-use systems remains rare and underdeveloped.

According to Gong et al. (2013), global land-use has been a source of major contention in international relations for centuries. From the systems of parcelled property of the feudal system to the gated agrarian communities of modern times, the way in which land is used, allocated and shared has been a major discussion point. With new and ever-advancing technology, modern day global land use has been revolutionized, with new insights and promises of sustainability leading the way. The traditional way a country governed its land-use was no different from the way it governed its laws: hierarchical, with all decisions dictated from the top-level down (Chaffin et al., 2016). This structure has become increasingly inadequate with the complexity and breadth of today's land-use challenges, leading to the development of a more decentralized system. The concept gives local and regional levels greater power and authority to make land use decisions, suggesting a more democratic approach to achieving sustainability (Chigbu, 2022). Increasing calls for innovative paradigms that toughen Local Agenda 21 through feasible decision-making processes, and sustainable utilization of lands and other natural resources drive the proposition of a novel approach '4R value strategy' that creates a clear path to land use governance and management at different scales.

1.2. Theoretical underpinnings and concepts

Fig. 2 draws on advocacy for innovative systems that sustainably anchor land use, urban and natural resources, amid concerns of Land Use and Land Cover Change (LULCC) being a critical mesoscale element that drives environmental change, health and impoverishment of several livelihoods. The scope of our study draws on the tenets of some standardized and a plethora of guiding concepts - including (i) Risks, disasters and vulnerability assessments (ii) land use governance (iii) United Nations 2030 Agenda for Sustainable Development (iv) Local Agenda 21 and (v) Transformative governance, equity and justice. Comprehensively, this study is among the rare and few mensurable studies that rigorously evaluates LUS in Africa and its sub-regions. Our study contributes to this emerging and attendant body of knowledge that synergizes the application of remote sensing and Geographic Information Systems (GIS), and land use governance.

In an attempt to critically assess LUSD in Africa, the present study through the framework presented above sought to:

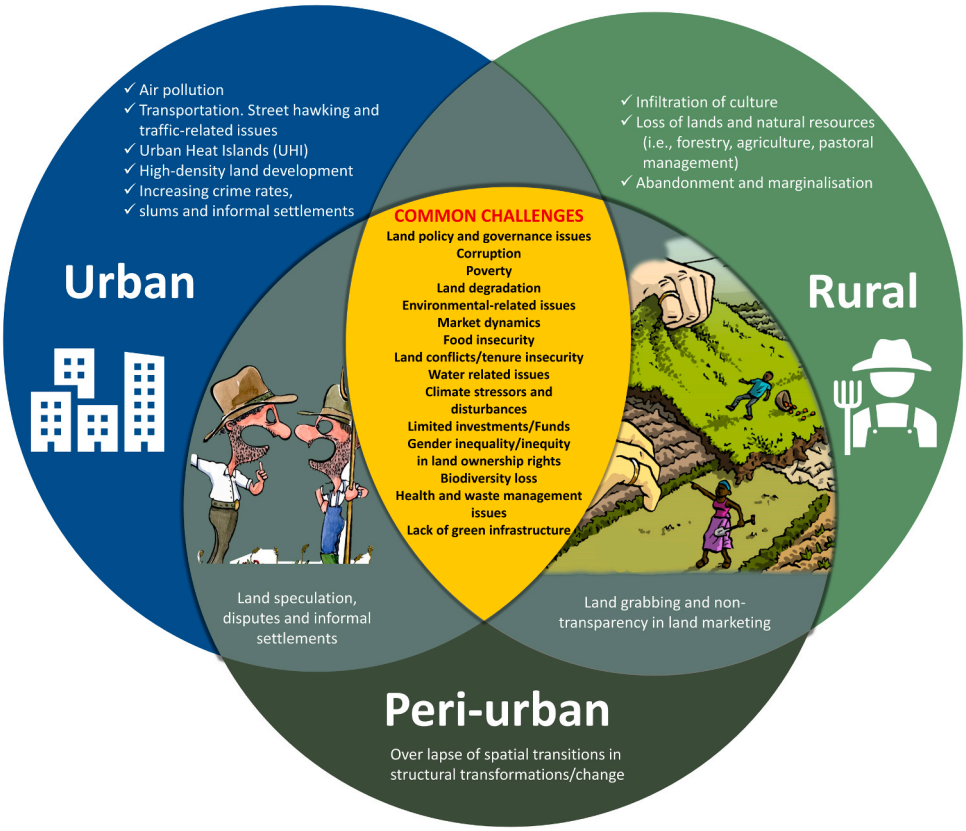

Fig. 1. Land-use challenges in three designated spatial zones of land use development. Source: Adopted and modified, Chigbu (2021).

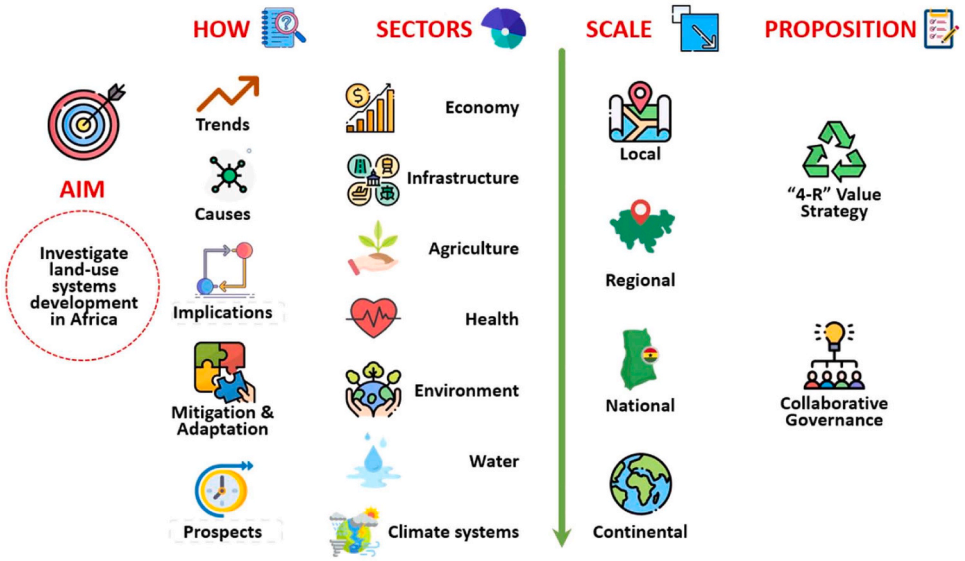

Fig. 2. Theoretical framework and the study objectives.

i. Assess the spatial distribution, driving forces and implications of Africa's LULCC over the past four decades.
ii. Make land use predictions based on current land use trends in Africa.
iii. Propose a novel construct that dwells on commonalities, unifies actions and addresses sustainability concerns identified across Africa's sub-regions.

The outcome of this study will enhance knowledge in Africa's land use systems development, and explicitly enrich basic datasets that informs and guides key stakeholders, as well as the international scientific community to circumvent the driving mechanisms and processes causing these undesired changes and implications on different fronts. The urgency and relevance of this study evolves from the need to develop a novel approach, characterized by "*empathy*" and "*social change or justice*" that propels sectoral players to find common grounds through unified actions towards a sustainable and a workable objective.

2. Methodology

2.1. Regional overview

Out of the world's total land area, Africa's proportion is about 30.2 million km^2 (i.e., 20.4 %). 60 % of Africa's terrain is characterised by "the plateau." The elevation is steadily lower from the southeast to northwest. The region is presently characterised by high temperature and aridity due to the north-south symmetry distributed climate zone, across the equator (Xiao et al., 2022). Fig. 3 depicts the geographical location of the African continent.

According to the National Remote Sensing Centre of China (2019), it is the second largest continent in the world and has the second largest population (about 1.37 billion). The region is endowed with abundant forest resources (constituting 13.85 % of the world's forest area of about 51, 400 ha). Table 1 presents 54 countries, categorised into five regions used for analysis.

Population density and annual growth rate statistics were computed using World Bank's 2020 datasets which can be accessed via (https://data.worldbank.org/indicator/SP.POP.TOTL?locations=ZG). The annual growth rate (%) was computed based on the expression (Eq. 1):

$$\text{Annual Growth Rate} = \left(\frac{V_{Present} - V_{Past}}{V_{Past}} \; x \; 100\right) \div N_{Years} \quad (1)$$

Table 1
Geographical distribution of countries in the study region.

Sub-Region (s)	Countries/Regions	Data gaps excluded
West Africa (WAF)	Benin, Burkina Faso, Cape Verde, Cote D'Ivoire, The Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Saint Helena (UK), Senegal, Sierra Leone and Togo	Saint Helena (UK)
East Africa (EAF)	Burundi, Comoros, Djibouti, Eritrea, Ethiopia, Kenya, Madagascar, Malawi, Mauritius, Mozambique, Reunion (France), Rwanda, Seychelles, Somalia and Somaliland, South Sudan, Tanzania.	Reunion (France) and Mayotte
North Africa/ Sahara (NAF/ SAH)	Algeria, Egypt, Libya, Morocco, Sudan, Tunisia, Western Sahara	Western Sahara
Central Africa (CAF)	Angola, Cameroon, Central African Republic, Chad, Democratic Republic (Kinshasa), Republic of Congo (Brazzville), Equatorial Guinea, Gabon, São Tomé & Príncipe	
Southern Africa (SAF)	Botswana, Lesotho, Namibia, South Africa and Swaziland	

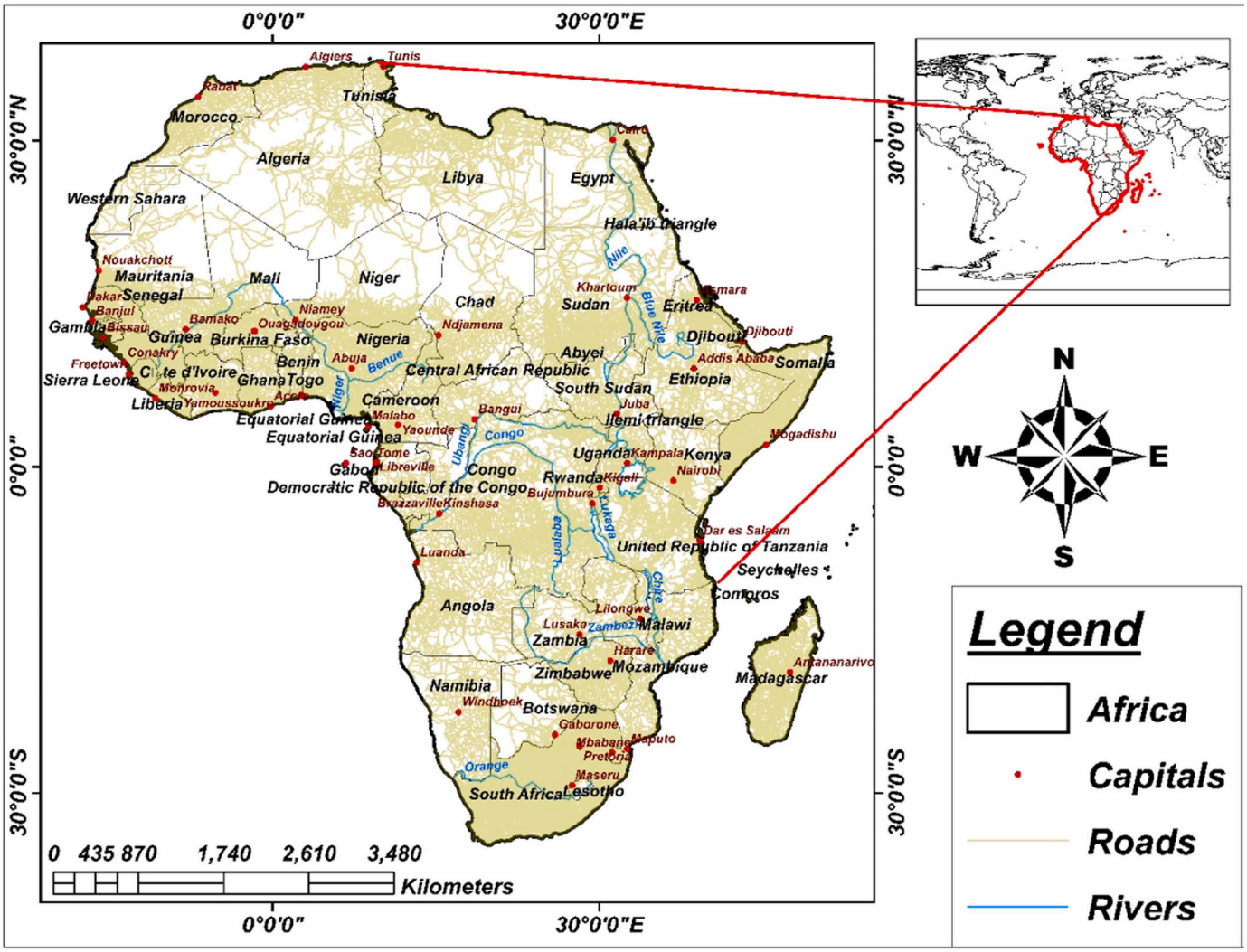

Fig. 3. Geographical location of the African continent.

Where $V_{Present}$ = Present or future value, V_{Past} = Base year or Past value, N_{Year} = Year interval or Number of years between the base and current years

Gong et al. (2013) asserted that Africa is the most challenging continent to map with regards to the process of generating global land cover (GLC) products. This is primarily due to the complexities and vegetative characteristics of the region. Table 2 highlights land cover mapping attempts at different scales in Africa, listed in chronological order.

2.2. Data acquisition and image classification

Landsat data (TM, ETM+ and OLI/TIRS) were acquired from the United States Geological Survey's (USGS) website (http://earthexplorer.usgs.gov/) for the assessment of land use and land cover changes (LULCC) in Africa. ArcGIS 10.8 and ENVI 5.3 were used for image pre-processing and enhancement. Other image pre-processing procedures performed include gap filling, image calibration, layer stacking and supervised classification. The band combinations used for layer stacking were 3, 2, and 1 for Landsat 4 and 5 TM and Landsat 7 ETM+, and 4,3,2 for Landsat 8 OLI/TIRS. These combinations were used to bring out the natural colour composite of the images at a resolution of 30 m.

Supervised classifications were employed to extract detailed LULC classes, including forests, farmlands/shrubs, grasslands, waterbodies, deserts, and built-up areas. The classification scheme of the six (6) classes (see Table A.1) were based on the USGS LULC classification system. A maximum likelihood classifier (MLC) was employed for preliminary classifications based on the results of the supervised classifications. To improve the accuracy of interpretation, some areas which were difficult to distinguish were inspected and validated with the aid of the Google Earth Pro software.

Fig. 4 presents the workflow designed for this study which constitute data source, image pre-processing and enhancement, post-classification, prediction and validation of satellite imagery.

2.3. Change detection analysis

We employed the post-classification change detection technique to ascertain the extent of change in Africa between 1980 and 2020. This facilitated the generation of statistical data on how land cover on the continent has changed across time in relation to the understudied features (forests, waterbodies, deserts, built-up, grasslands and farmlands/shrubs). Cross tabulation evaluation on a pixel-by-pixel basis aided in the estimation of land conversions from a particular land cover class to other forms, and their corresponding area over the given study period. The following expressions were used for the quantification of the rate of change (%) in land use/landcover (LULC) (Eq. 2), magnitude of change in LULC annually (Eq. 3), and the annual rate of change (%) in LULC (Eq. 4):

$$\text{Rate of change in LULC (\%)} = \frac{U_i - U_j}{U_j} \times 100\% \quad (2)$$

$$\text{Magnitude of Change in LULC per year} = \left[\left(U_i - U_j\right) \right] \div 40\text{years} \quad (3)$$

$$\text{Annual Rate of Change in LULC (\%)} = \left[\left(\frac{U_i - U_j}{U_j} \right) \times 100\% \right] \div 40\text{years} \quad (4)$$

Indicatively;

U_i denotes the final year under study, thus, the year 2020 within the context of the present study; U_j means the initial year being studied, thus, the year 1980. The annual rate of change in LULC was estimated to investigate the gains/expansion and losses/reduction in areas covered by the understudied land use classes over the past 40 years per the study duration (1980–2020). This provides detailed information on how changes occurred annually to ascertain the major events, transitions and underlying mechanisms that drove such changes.

2.4. Land use prediction and validation

Predictions for 2030, 2040, and 2050 were made using Modules for Land Use Change Evaluation (MOLUSCE) in QGIS version 2.18.24. It utilizes Cellular Automata - Artificial Neural Network (CA-ANN) techniques and simulations to forecast LULCC scenarios in Africa, utilising 2010 and 2020 LUCC maps. The analysis primarily encapsulates Evaluating Correlation (EC), area changes, Transition Potential Computation (TPC) modelling and validation based on four (4) iterations. Digital Elevation Model (DEM) and a road raster georeferenced image of Africa were used as reference data for the predictions. The main predictor variables used as reference for future projections constitute *built- environment* (i.e., likelihood of change, density of developed lands and crop land and transportation), *socio-economy* (i.e., population density, number of households, urban population density, urbanisation and industrialization), and *natural environment* (i.e., climatic variables-temperature, precipitation and moisture; ecology and topography).

In forecasting LULCC in Africa (Fig. 5), the model's first stage integrates LULC maps for the base periods (2010 and 2020) for predicate

Table 2
Historical national, regional and continental land cover (LC) mapping attempts.

Coverage	Period	Sensor	LC Type	Resolution	Classification Method	Source
Entire Africa	1982–1983	NOAA-AVHRR	Multiple	4 km	Principal Component	Tucker et al. (1985)
Entire Africa	2000	SPOT-VGT (GLC2000)	Multiple	1 km	Unsupervised ISODATA	Mayaux et al. (2004)
Sub-Saharan Africa	2005	MODIS	Rainforest cover	250 m	Unsupervised ISODATA	Mayaux et al. (2013)
West Africa	2006	MODIS VI ASAR-TDX/TSX	Multiple	250 m	Supervised (RF, DT-MLA)	Gessner et al. (2015)
Entire Africa (GLC v.1)	2014	Landsat 8 OLI & Landsat 5,7	Multiple	30 m	Supervised (RF, DT-MLA)	Feng et al. (2016)
Entire Africa	2003–2014	MODIS NDVI	Cropland	250 m	Supervised (DT-Algorithm)	Xiong et al. (2017a)
West African Sudan Savanna	2013	Landsat 8 OLI MODIS VI, LC	Cropland	250 m	Supervised (RF-MLA)	Forkuor et al. (2017)
Entire Africa	2000–2015	Landsat 7 ETM+	Multiple	30 m	Supervised (RF, DT-MLA)	Midekisa et al. (2017)
Entire Africa	2015	Sentinel-2 MSI, Landsat 8 OLI	Cropland	30 m	Supervised (RF, SVM-ML)	Xiong et al. (2017b)
Entire Africa (GLC v.2)	2015	Landsat 8 OLI MODIS NDVI	Multiple	30 m	Supervised (RF-MLA)	Feng et al. (2018)
Southern Africa	2008	Landsat 5,7 ALOS-PALSAR	Savanna Woody Cover	30 m	Supervised (RF-MLA)	Symeonakis et al. (2018)
Liberia and Gabon	2015	Landsat 8 OLI	Multiple	30 m	Supervised (RF-MLA)	De Sousa et al. (2020)
West African Sahel	2015	Landsat 8 OLI	Cropland	30 m	Supervised (RF-MLA)	Samasse et al. (2020)

RF=Random Forest; MLA=Machine Learning Algorithm; SVM=Support Vector Machine; DT=Decision Trees
Source: Adapted and modified from Radwan et al. (2021)

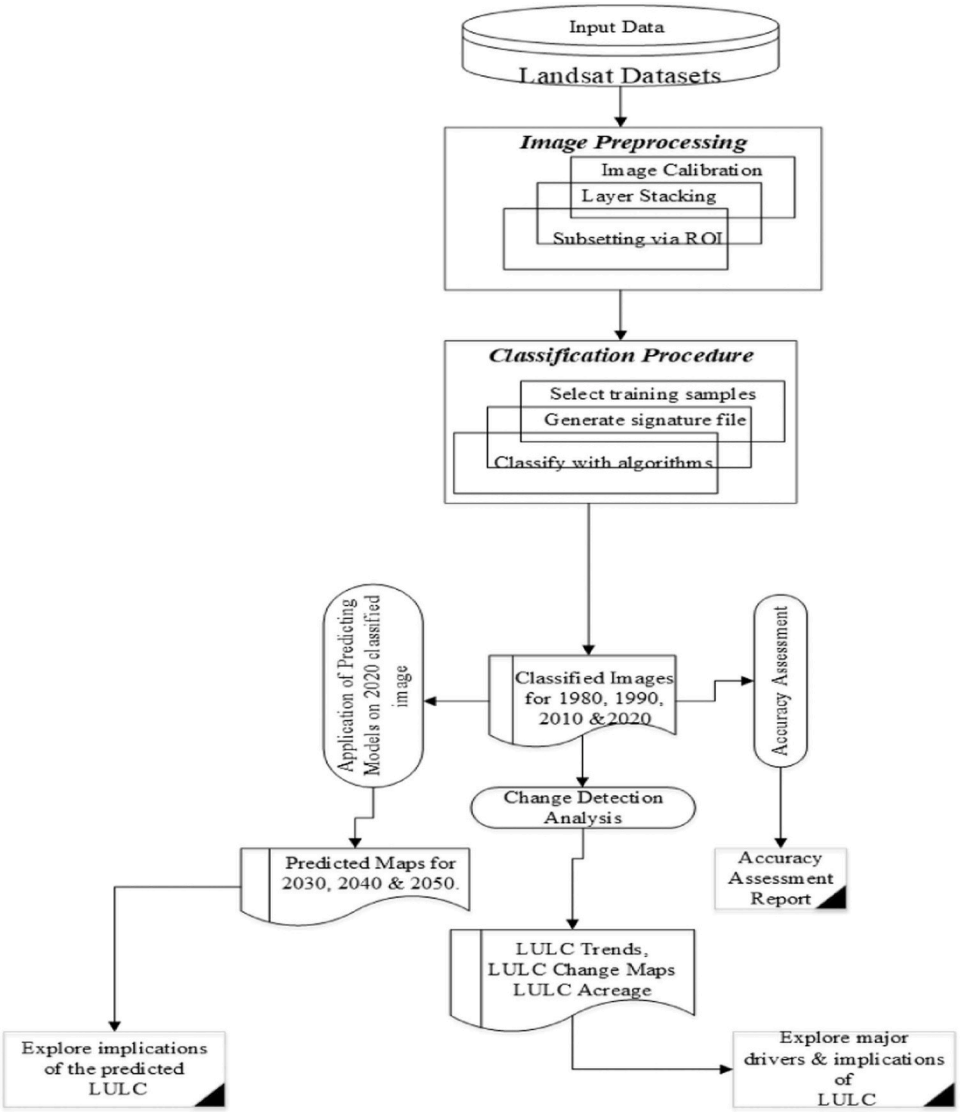

Fig. 4. Flowchart designed for this study.

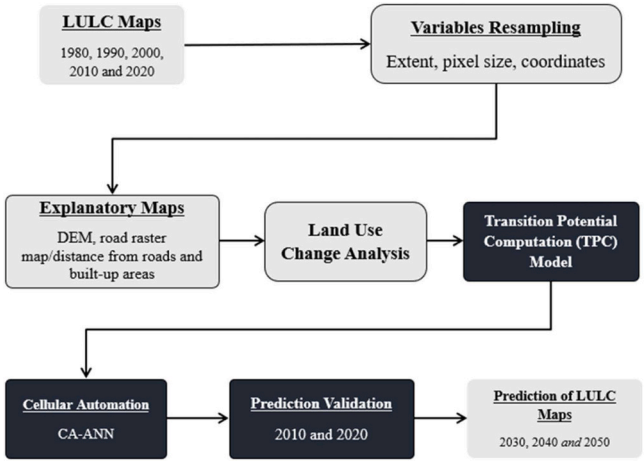

Fig. 5. Procedures for Africa's land-use change predictions.

2030, 2040 and 2050. Inputs are incorporated in the model to generate LCC map, from which the changing trends for the study setting between 2010 and 2020 are generated. These parameters constitute DEM, distance from roads, and built-up density. Using Pearson's correlation, Crammer's coefficient and Joint Information uncertainty, the link between geographic variables given the two raster images employed for this relationship is examined. Various classifications for Africa along with the region's dynamics are computed between the base period (2010) and the final year (2020). The TPC plug-in utilizes some machine learning algorithms (such as artificial neural networks (ANN) and logistic regression (LC)), weights of evidence (WoE), and some multi-criteria evaluation (MCE) to create TPC maps. These techniques or procedures draw on geographic information and LULC data to construct and calibrate changes in the region. ANN was applied to make predictions for 2030, 2040 and 2050. A confusion matrix that merges and improves the user and producer accuracy assessments were used to gauge accuracy rates.

2.5. Accuracy assessment

For each given period (see Fig.A.1), validation of satellite imagery was performed using ENVI 5.3 and ArcGIS 10.8 to ground truth selected points from random geographical locations. The images were verified by overlaying them on Google Earth Pro. For precision assessment, 500 samples were obtained from each class (i.e., deserts, built-up,

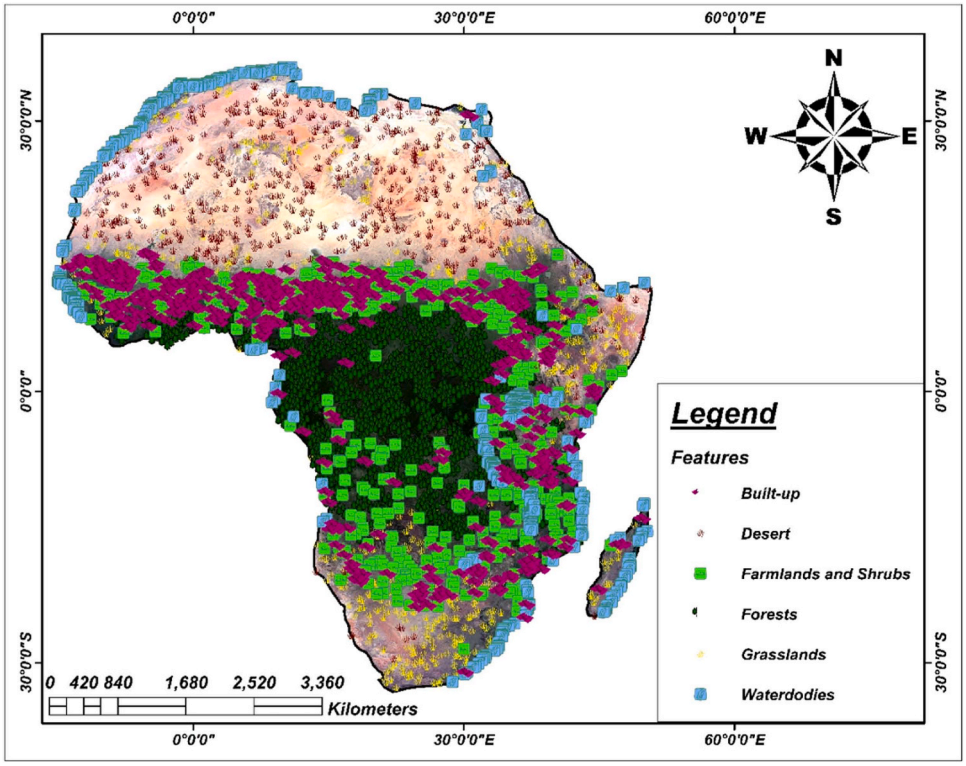

Fig. 6. Validation of satellite imagery for the given classes over the given study duration (1980s – 2022).

waterbodies, forests, grasslands and farmland/shrubs) in the characterized imagery (Fig. 6), making a total of three thousand samples.

We employed Congalton (1991) confusion matrices, cited in Sarfo et al. (2022) study (Eq. 5) to validate the spatial results obtained for this study. This standardized matrix (https://pages.cms.hu-berlin.de/EOL/geo_rs/S10_Accuracy_assessment.html#Confusion_matrix) combines and improves upon the user and producer accuracy assessments has been applied by several scholars and research institutes across the globe to ensure validity and accuracy in images generated.

Here:

A. A=Accuracy Assessment

T.S.P = Total Sample Points obtained (T.S. P=3000)

A.S.P = Average number of sample points that accurately fall on each required feature (A.S. P=2850)

$$A.A(\%) = [(A.S.P/T.S.P) \times 100] \quad (5)$$

$$A.A(\%) = [(2850/3000) \times 100]$$

A 95 % accuracy rate was obtained for the satellite imagery generated for this study. This indicates images used for the spatial analysis are valid and can be used for further analysis or to draw logical conclusions.

3. Results

3.1. Analysis of LULCC in Africa

Spatial trends of LULCC in Africa for 1980, 1990, 2000, 2010 and 2020 are shown in Table 3 and Fig. 7 (refer to Table A.2 for regional area coverage and LULCC analysis). In 1980, forests and deserts were the dominant classes, followed by cultivated areas and lowlands (herein termed as farmlands/shrubs), particularly in the eastern, central and western parts of the continent. In 1990, the built environment amplified steadily, replacing deserts, farmlands and shrubs. Historical observations and available literature based on the "*urban-rural divide*" and the "*pull or push theory*" (Xiao et al., 2022; Radwan et al., 2021; Marchant et al., 2018) suggest that the drastic changes identified across different nations in Africa post-independence were developed for residential, business, educational and agricultural purposes. This substantively explains why built-up areas have continuously increased during the last 40 years at the expense of grasslands, farmlands/shrubs and deserts.

3.2. Temporal variations of LULC in Africa

The temporal variations of LULC in five-time windows: 1980–1990, 1990–2000, 2000–2010, 2010–2020 and 1980–2020 are shown in Table 4. In terms of change in the area over the past four decades, Africa

Table 3
Area coverage (sq.km) for LUCC in Africa (1980–2020).

Classes	1980s	1990s	2000s	2010	2020
Farmlands and shrubs	5,507,600	5,292,884	5,158,041	5,165,026	4,798,460
Desert	6,199,124	5,893,299	5,200,863	5,003,458	5,168,974
Built-up	799,642	1,078,742	1,293,155	1,397,324	2,531,036
Grasslands	3,646,222	3,859,116	4,451,938	4,627,173	3,041,842
Forests	13,932,541	13,939,830	13,938,008	13,935,578	14,304,287
Waterbodies	284,871	306,130	327,996	241,442	525,401

***Total area coverage (Km^2) (Absolute) = 30,370,000

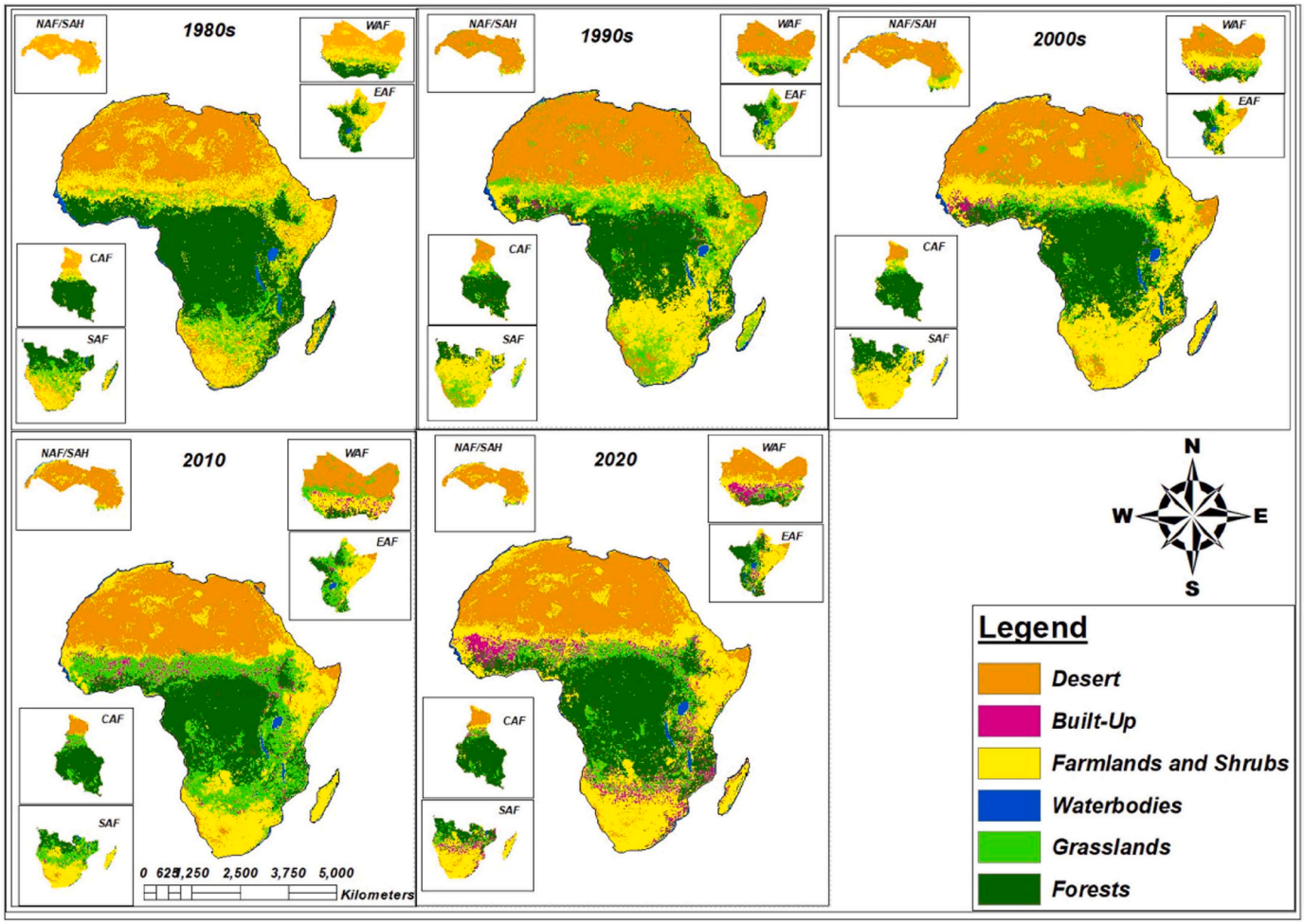

Fig. 7. Classified LULCC map of Africa between 1980 and 2020.

Table 4
Land cover changes between the given study periods (%).

Classes	1980s-1990s	1990s-2000s	2000s-2010	2010-2020	1980s-2020
Farmlands and shrubs	-3.89	-2.55	+0.14	-7.09	-12.88
Desert	-4.93	-11.75	-3.79	+3.31	-16.62
Built-up	+34.9	+19.88	+8.06	+81.14	+216.52
Grasslands	+5.84	+15.36	+3.94	-34.26	-16.58
Forests	+0.05	-0.01	-0.02	+2.65	+2.67
Waterbodies	+7.46	+7.14	-26.39	+117.61	+84.44

has experienced a fundamental drift in built-up (+216 %) and waterbodies (+84 %). Interestingly, the continent per evidence provided during the past 40 years is currently experiencing a regrowth in its forests (+2.67 %). Deserts (-16.62 %), farmlands/shrubs (-12.88 %) and grasslands (-16.58 %) have experienced a steady decline, as these land use types have been converted to built-up, forests or submerged by water. Kindly refer to the supplementary material (Table A.3) for each sub-region's variations.

Table 5 presents statistics for the rate and magnitude of change, in relation to LULCC in Africa over the past 40 years.

Table 5 depicts farmlands/shrubs, deserts and grasslands decreased at an annual rate of 0.32 %, 0.42 % and 0.41 %, respectively. In the same vein, built-up, forests and areas covered by waterbodies increased annually at a rate of 5.41 %, 0.07 % and 2.1 %, respectively. Refer to the supplementary material (Table A.4) for changes in each region's classes per the given study period.

3.3. *Africa's population density, annual growth rates and urban hotspots*

A surge of recent and early studies has highlighted population growth and distribution, as well as urbanization (i.e., through migration and indigenous growth) as primary drivers of LUC. Population growth and urbanization are key drivers with "*causal chain*" effects due to a host of socio-economic needs, tied to them; thus, both factors drive and/or

Table 5
Rate and magnitude of change (sq.km) of LULCC in Africa (1980–2020).

Classes	1980s (sq.km)	2020 (sq.km)	Magnitude of change (sq.km)	Magnitude of change (sq.km)/year	Annual Rate of change (%)
Farmlands and shrubs	5,507,600	4,798,460	-709140	-17728.5	-0.32
Desert	6,199,124	5,168,974	-1030150	-25753.75	-0.42
Built-up	799,642	2,531,036	+1731394	+43284.85	+5.41
Grasslands	3,646,222	3,041,842	-604380	-15109.5	-0.41
Forests	13,932,541	14,304,287	+371746	+9293.65	+0.07
Waterbodies	284,871	525,401	+240530	+6013.25	+2.1

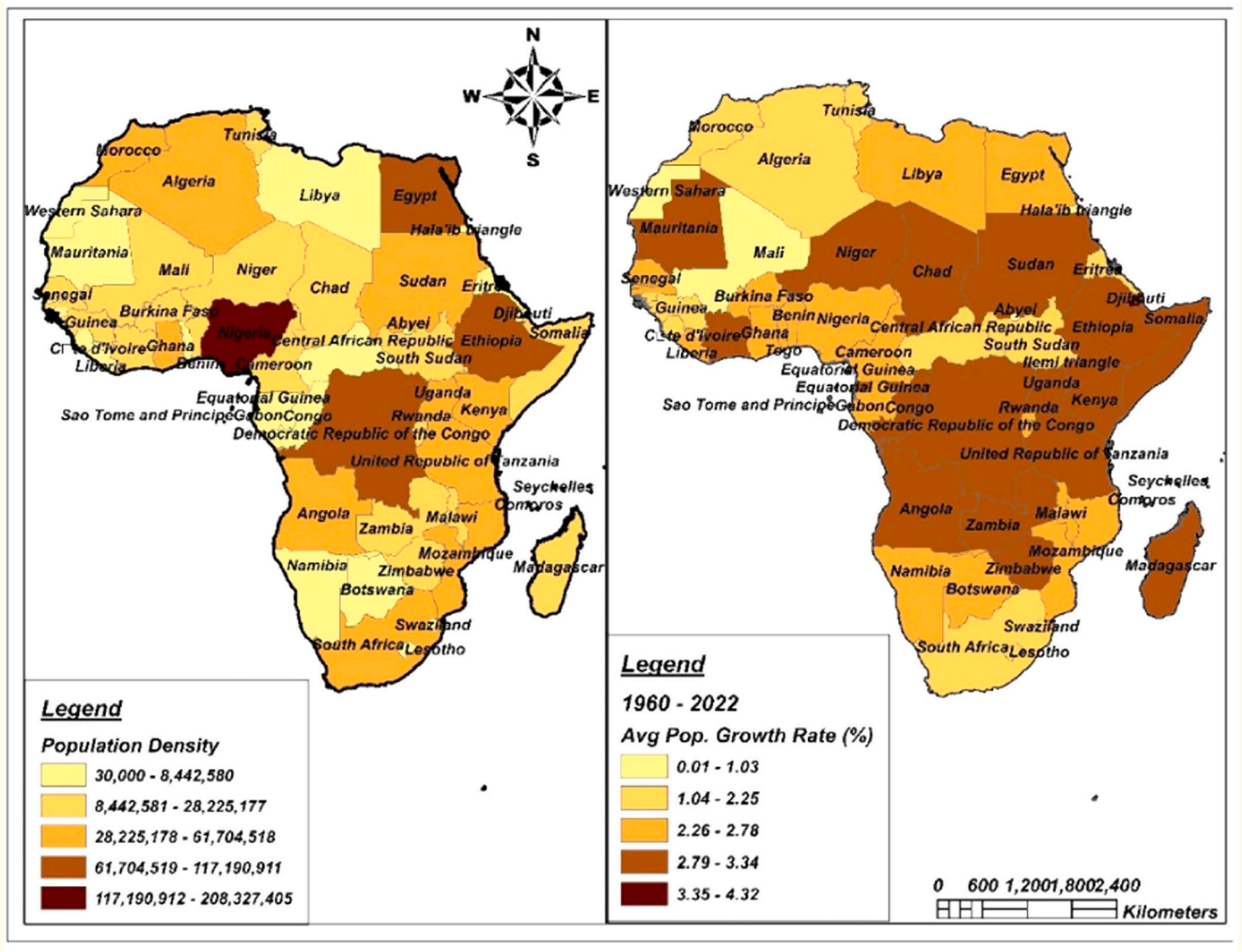

Fig. 8. Africa's population density and annual growth rates.

are driven by cultural, economic, social and environmental processes that influence transformations in the current age of anthropocene. Figs. 8–9 show the population density, annual growth rates (i.e., 1960–2020), and urban hotspots in Africa.

Evidence presented in Fig. 8 shows that the eastern and central parts of Africa have high population density, compared to other sub-regions. Moreso, the area is characterized by an annual average growth rate of 2.79–3.34 percent. Nigeria, on the other hand, despite being the most populated nation in Africa has a mean annual growth rate of 2.26–2.78 percent like other nations in its region. Population and Housing Census (PHC) carried out across Africa indicates most nations have grown in five-folds since independence (UN-Habitat, 2019; UN-World Population Prospects, 2019).

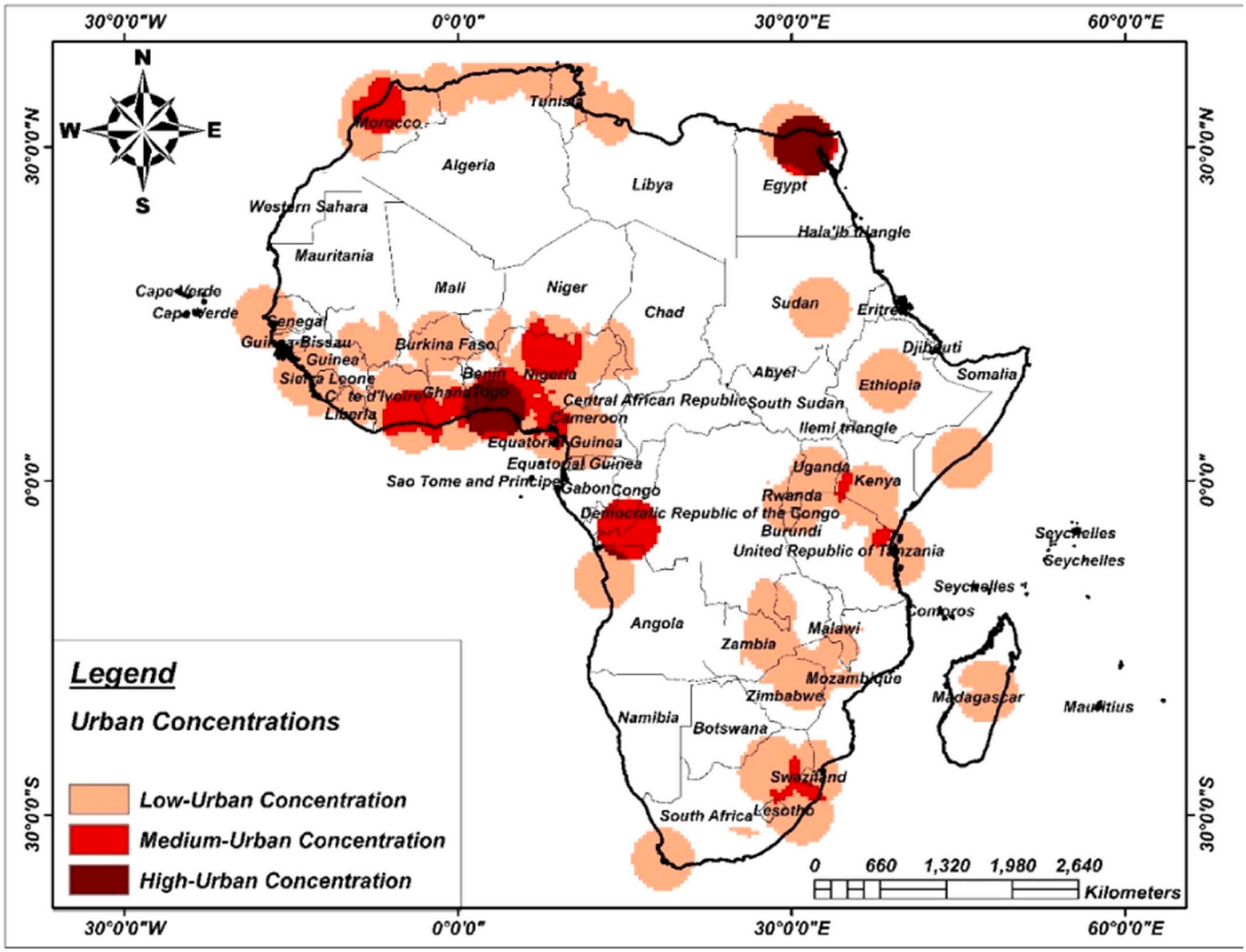

Fig. 9. Urbanization hotspots across Africa's sub-regions.

The urban concentration map of Africa (Fig. 9) shows that some countries along the peripheral zones of WAF like Cote D'Ivoire, the Republic of Ghana, Benin, Togo and Nigeria, have medium to high urbanization rates. In CAF, the Democratic Republic of Congo has a moderate urbanization rate among countries in the region. Kenya and Tanzania have fairly been experiencing increasing urbanization in EAF, likewise, Swaziland and Lesotho in SAF. In NAF/SAH region, Egypt and Morocco have been experiencing medium-to-high urbanization rates. Based on the evidence presented in Fig. 9, it is clear that urbanization rates are dominant in WAF, followed by EAF and SAF. A close observation in NAF/SAH shows increasing urbanization rates in Morocco, Algeria and Tunisia.

3.4. Future LULC projections for Africa: The '4R value strategy' as a transformative path to land use sustainability

Modeling future LULCC resulting from the core and potential drivers (Fig. 10) identified through this study is relevant for developing garden, sponge, low-carbon and resilient cities across Africa based on the grand urban model. The complex web of examining regional and teleconnected drivers of LULCC on macro-and-microeconomic scales remains a daunting task for most researchers. This calls for a thorough understanding of key issues underlying the subject of contention, through the proposed construct "*4R value strategy*" in drifting from locational-and-pattern-based studies to a process-based mode of grasping and addressing diverse and multifaceted factors influencing Africa's land use development. Micro-and-macro factors that drive changes in land use systems at various levels (i.e., local to the global level) are often anthropocentric and biophysical in nature. Recent reports according to Chigbu (2022) and UN-Habitat (2019) project urban population to grow 175 % by 2030. The UN-Habitat (2019) further projects that about 70 % more agricultural lands will be required by 2050. Their report further highlights dire consequences on key economic sectors, if the target is not realized. Additionally, an increase in the intensity and frequency of climate hazards in recent decades will further displace or compel vulnerable groups in urban, peri-urban and rural areas to relocate. Hence, unified actions are required to build resilience against or avert impending climate hazards.

The change detection statistics (Tables 6–8) for predicted land-use trends in Africa (Fig. 11) indicate farmlands and shrubs (+141.74 %), built-up areas (+81.42 %) and deserts (+24.52 %) are the primary land cover classes that will experience fundamental drift (i.e., will increase massively) over the study period (2020–2050). Contrarily, grasslands (-87.44 %), forests (-50.92 %) and areas covered by waterbodies (-35.54 %) will experience a sharp/steady decline over time (Fig. 11). Moreso, the rate and magnitude of change analyses show farmlands/shrubs, built-up and deserts will amplify at an annual rate of +4.7 %, +2.71 % and +0.82 % respectively, replacing other classes like

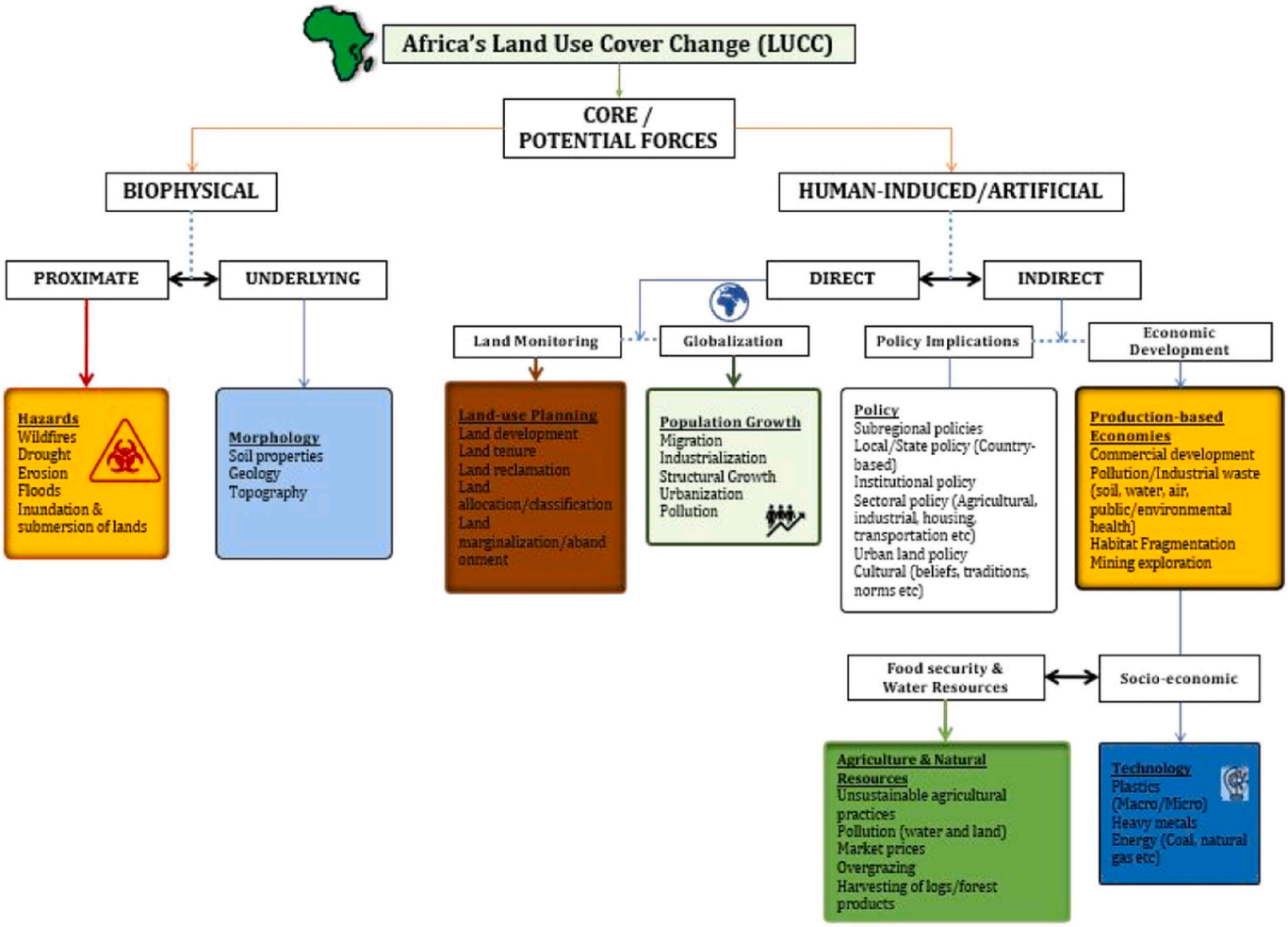

Fig. 10. Illustration of drivers influencing land use systems in Africa. Source: Authors' Construct.

Table 6
Area coverage (sq.km) for LULCC in Africa based on future projections (2020–2050).

Classes	2020	2030	2040	2050
Farmlands and shrubs	4,798,460	6,125,200	9,933,709	11,599,773
Desert	5,168,974	6,993,143	7,095,852	6,436,387
Built-up	2,531,036	3,049,413	4,275,589	4,591,736
Grasslands	3,041,842	2,180,673	400,000	382,121
Forests	14,304,287	11,684,402	8,317,223	7,021,321
Waterbodies	525,401	337,168	347,627	338,662

***Total area coverage (Km^2) (Absolute area) = 30,370,000

grasslands and forests. Similarly, grasslands, forests and areas covered by waterbodies will experience annual reduction rates of 2.92 %, 1.69 % and −1.19 %, respectively.

4. Discussion

4.1. Regional-based analysis, influences and implications of LULCC in Africa

Understanding the complexity and encompassing nature of LULCC requires critical monitoring, holistic and a multidisciplinary approach, which are not just limited to the extent and location of variation, but to

Table 7
Land cover changes between the given study periods (%) (2020–2050).

Classes	2020-2030	2030-2040	2040-2050	2020-2050
Farmlands and shrubs	+27.65	+62.18	+16.77	+141.74
Desert	+35.29	+1.47	-9.29	+24.52
Built-up	+20.48	+40.21	+7.39	+81.42
Grasslands	-28.31	-81.66	-4.47	-87.44
Forests	-18.32	-28.82	-15.58	-50.92
Waterbodies	-35.83	+3.1	-2.58	-35.54

Table 8
Rate and magnitude of change (sq.km) of LULCC in Africa (2020–2050).

Classes	2020 (sq.km)	2050 (sq.km)	Magnitude of change (sq.km)	Magnitude of change (sq.km)/year	Annual Rate of change (%)
Farmlands and shrubs	4,798,460	11,599,773	+6801313	+226710.43	+4.7
Desert	5,168,974	6,436,387	+1267413	+42247.1	+0.82
Built-up	2,531,036	4,591,736	+2060700	+68690	+2.71
Grasslands	3,041,842	382,121	-2659721	-88657.37	-2.92
Forests	14,304,287	7,021,321	-7282966	-242765.53	-1.69
Waterbodies	525,401	338,662	-186739	-6224.63	-1.19

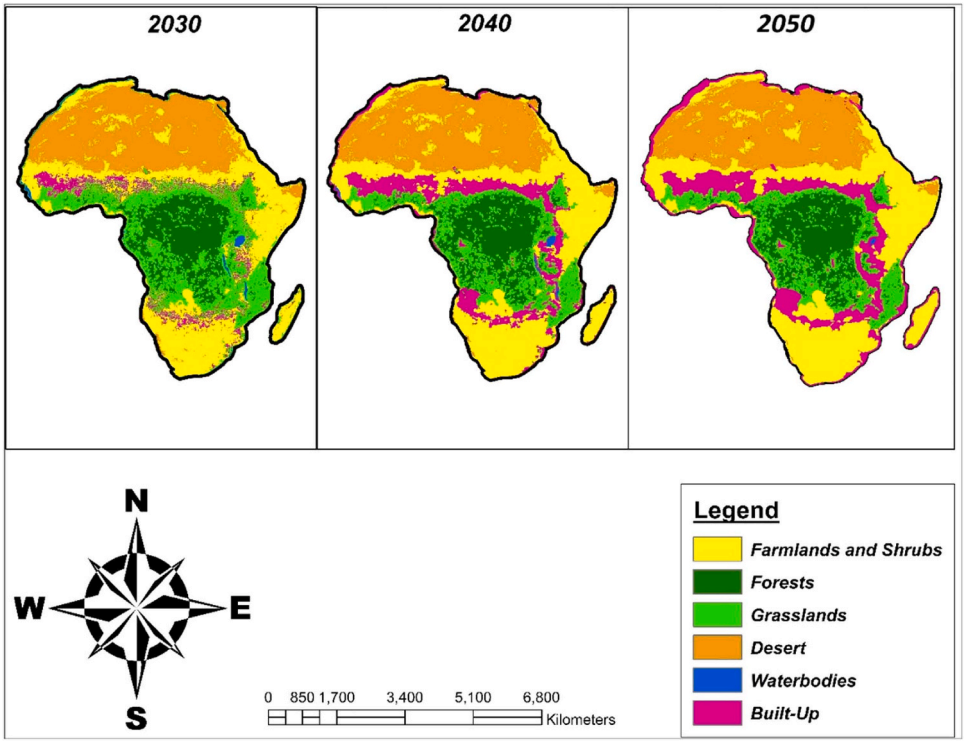

Fig. 11. Predicted land use and land cover trends in Africa.

spatial patterns of fragmentation and growth. A summary of influential factors driving LULCC in each sub-region is presented in Table 9.

4.2. Northern Africa (NAF/SAH)

NAF/SAH is characterized by generic land covers of deserts, farmlands/shrubs, grasslands, forests, the built-environment, waterbodies and depressions with uneven (diverse) proportions. Libya, Algeria, Tunisia and Morocco have relatively higher amounts of forest, as compared to Egypt and Sudan (Fig. 7). Egypt, on the other hand, has flooded areas and depressions which favor irrigation agriculture due to the presence (influence) of the Nile (Schilling et al., 2020). These land covers have over the decades been transformed by land use activities which comprise of rainfed and irrigation agriculture, built-environment for settlement, industrial and infrastructural developments. Anthropogenic factors have accelerated the transition of land covers due to the exponential growth in population. NAF/SAH has a population of 255 million with Egypt as the most populous nation in the region with 104 million, whilst Western Sahara has the least population of 597,339 according to UN Population Division's report on the prospects of the World's Population (2019). Recent studies by Radwan et al. (2019), Bakr and Bahnassy (2019), and revealed the Greater Cairo region in Egypt has experienced population growth in 30-fold over the last century. They further reported 7.73 % of vegetation and 8.7 % of barren and desert land covers had been lost to built-up. The expansion of Greater Cairo region has taken place on vegetated and rich agricultural lands, in addition to the agglomeration of fringes located at the borders of the region.

In Morocco, population increase is on a steady growth path of 37 million in 2022 from 35 million in 2017. Recent surge in literature, particularly, the studies conducted by Mohajane et al. (2018) in the Azrou forest revealed that the high density of the forest increased, as barren areas were converted to forests. This has eventually sustained forests in the region, over the past three decades (1987–2017). Similarly, Moumane et al. (2022) on the Ternata Oasis in Morocco identified 5 land cover classes of cultivated land, bare land/deserts, water and

Table 9
Summary of identified LUCC drivers across Africa's sub-regions.

Sub-regions	Core and Potential Driving Forces Direct and Indirect							
	PGD	UP/US	AE	CH/T/BF	T	FF/WF/BF	WGP	Others
NAF/SAH	√√√	√√	√√√	√√	√√√	√√	X	*Re-use of deserts/bare land *Urban agriculture, greening, browning and circular economies. *Industrialization *Grazing/pasture lands
WAF	√√√	√√√	√√√	√√	√√	√√	√√√	*Cultural factors: Public Behavior/lifestyles, norms and traditions, beliefs and so on. *Deforestation *Re-afforestation, Urban Agriculture, greening, browning and circular economies. *Industrialization *Illegal & Unregulated mining activities
EAF	√√√	√√√	√√√	√√√	√√√	√√	√√√	*Illegal & Unregulated mining activities *Industrialization *Deforestation
CAF	√√√	√√√	√√	√√√	√√	√√√	√√√	*Industrialization and investments in profit-oriented sectors by multinational/transnational companies (colonial ties) as observed in the case of Gabon. *Deforestation
SAF	√√	√√√	√√√	√√√	√√√	√√√	√√	*Overused pastures/arable and pasture land expansion, mining activities, deforestation (soil and forest degradation) and intensive harvesting of fuelwood/timber from the natural forest. *Creation of artificial forests to augment conservation efforts. *Cultural factors: Public Behavior/lifestyles, norms and traditions, beliefs and so on. *Illegal & Unregulated mining activities *Technological advancements

*√=Magnitude/Degree of influence; X=None; PGD=Population Growth and Distribution; UP/US=Urban Primacy/Urban Sprawl; AE=Agricultural extensiveness/expansion; CH/T/BF=Climate Hazards/Topography/Biophysical Factors; T=Technology; FF/WF/BF=Forest Fires/Wildfires/Bushfires; WGP=Weak Governance/Institutional Systems and Policies

built-up areas. They reported a continuous decline in deserts (65–57.1 % from 1991 to 2021) and an increase in built-up areas (1–3.21 %). In Algeria, a trend in the reduction of forests and agricultural lands were observed, as population ascended, particularly from 2008 to 2017 in the region of Tiaret (Amrouni et al., 2022). Primary LULCC drivers of anthropogenic and climate hazards pose devastating implications to NAF/SAH, particularly, water scarcity, food production and conflicts in resource use and ownership. This triggers the essence of on-going discourse on 'water', being regarded as the next 'gold' for the current and next generations.

Between 1980 and 2020, change detection analysis based on the spatial results for the entire NAF/SAH region (refer to supplementary material, Table 3A) reveals farmlands/shrubs and deserts experienced a subtle decline at a rate of 39.35 % and 74.84 %, respectively. Conversely, built-up, grasslands, forests and areas covered by water-bodies increased dramatically at a rate of 4474.33 %, 32772.95 %, 715.41 % and 1564.75 %, in that order. A close observation and the extant literature reviewed corroborates with the findings of medium to large scale studies conducted in the region, as highlighted in this section. Interestingly, based on evidence presented, the NAF region might be

experiencing regrowth/greening "*land use and recover changes (LURC)*" considering the massive gains and shift in grasslands, forests and waterbodies, despite the dramatic increase in built environment over the past 40 years. This may largely be as a result of urban greening and browning, urban agriculture, as well as the extensiveness of blue, green or grey economies in re-utilizing deserts/bare land and cultivated zones in the NAF region.

4.2.1. Climate variation, food security and water scarcity

Given the climate of Northern Africa, the trade-off of vegetation for built-up has resulted in the increase of average surface temperature from 38.4°C in 1990–42.1 ° C in 2016, at a peak of 52.71 ° C. In Cairo for instance, the increase in surface temperatures has negative impacts on people (Pal and Ziaul, 2016), in addition to environmental processes such as increasing evaporation rates, air pollution, wind turbulence and alteration in the water balance (Tran et al., 2017). Again, given the geomorphology and the dominance of the desert and bare land in NAF/SAH, coupled with increasing surface temperature and rainfall variability, prevailing conditions will be altered in the southern part of the Mediterranean basin (Prudhomme et al., 2014). Tramblay et al. (2018) reported that climate hazards altered about 46 basins that supply the largest dams and reservoirs in North Africa drawing on climate scenarios of a reduction in precipitation, and increasing evapotranspiration along the west to east gradient during late spring and early fall. Again, increasing temperatures have amplified the rate of ice cover loss in mountains of Morocco (Marchane et al., 2017).

Moreso, rapid population growth and economic development (Milano et al., 2012) were factored into simulated future water resources for Maghred using demand and supply. Droogers et al. (2012) predicted a reduction in water supply by 12 % on average, against a strong increase in demand for water by more than 50 %. Also, studies on hydrological scenarios using individual countries such as Algeria (Benhamiche et al., 2014), Morocco (Brouziyne et al., 2018) and Tunisia (Dakhlaoui et al., 2017) are under severe risk of water scarcity. Schilling et al. (2020) reported a decline in surface flows that is more pronounced under the Representative Concentration Pathway (RCP) 8.5 scenario. In the case of Libya (Brika, 2018), the nation has been identified as water stressed/water insecure, being reliant on a total of 3890 mm^3 groundwater, surface water and desalinated water in 2012 (Aqeil et al., 2012). Out of this volume, agriculture and domestic purposes utilize about 83 % and 12 %, respectively, whilst 5 % is allotted for industrial purposes. Some parts of the country receive little or no rain (Brika, 2018). 90 % of the entire Libyan population are concentrated along the country's coastlines. Global water scarcity status ranges from the number of people facing this phenomenon for at least 4–6 months per year, thus, about 1.8–2.9 billion. Half a billion people face water scarcity all year round (Mekonnen and Hoekstra, 2016). For instance, according to Mekonnen and Hoekstra (2016), Libya and Somalia (80–90 %) and Pakistan, Morocco, Niger and Jordan (50–55 %) have more than 50 % of their population experiencing water scarcity through-out the year.

As a result of water scarcity, there is a significant decline in the availability and accessibility of portable and quality water, as well as water supply to dams and reservoirs which affect irrigation and industrial activities (Lezzaik and Milewski, 2018). Reduction in groundwater recharge based on the standpoints of Benabdallah et al. (2018) is associated with the extraction of groundwater in Maghreb countries, resulting in a decline and pollution of water aquifers. Overall, NAF is considered to be one of the driest regions in the world. However, some countries such as Algeria, and Tunisia are more water secured, compared to Egypt and Morocco, whilst the worst hit is Libya with dire consequences. The threats posed by water scarcity and insecurity have a direct relationship with food production based on the sector's sensitivity to climatic conditions. The production of cereals such as durum wheat in Algeria is expected to reduce by an average of 31 % from 2071 (Chourghal et al., 2016). Egypt is expected to see a reduction in its wheat yields, despite heavy investments in irrigation (Asseng et al., 2018). In the case of Libya, Fader et al. (2016) argues that even if irrigation technologies and positive outcomes of climate change are considered, Libya will still not be able to reach its water requirements toward the end of the century (Harmanny and Malek, 2019). Similar outcomes are expected for Morocco (Ouraich and Tyner, 2018) and Tunisia with a 0.79 % decline in the production of cereals (Zouabi and Peridy, 2015). Presently, nations in NAF/SAH produce and import cereals. Egypt is the largest producer and importer, followed by Morocco and Libya with the lowest per capita production and the highest dependency on cereal imports (Schilling et al., 2020).

4.2.2. Resource-based related conflicts

The direct relationship between water security and food production is threatened by climate stressors and disturbances. Climate hazards do not solely pose threats to water resources and food security, but further translate the insecurities into economic mishaps which have reverberating effects on resilience and overall livelihood prospects in the NAF region (Waha et al., 2017). Food and water scarcity could propel demand and competition for land, water and other valuable resources. These needs and competing demands could create conflicts among regions, communities, neighboring countries and so on. In addition, population growth will further widen the supply and demand gap. Even though these gaps can trigger conflicts, the nexus between climate change, population and conflict is not direct but a complex one (Adams et al., 2018; Mach et al., 2019). Despite the complexity, scholars such as Scheffran et al. (2019) and Waha et al. (2017) argue that food insecurity can lead to riots and protests against the government. The history of riots and brutal violence led to division in a country like Sudan (Beber et al., 2014), coupled with protests and riots that led to political change/unrest in Tunisia, Libya and Egypt (Sottilotta, 2015). This impasse raises a cause for alarm since these insecurities could trigger more.

The Arab springs characterized by increasing food prices and living costs (Johnstone and Mazo, 2011), coupled with riots and demonstrations in Morocco and Algeria serve as a reference point in relation to indirect and perilous consequences of climate change and land use systems (Werrell and Femia, 2013) through competing interests. A decade ago, the drop in wheat production in China led to an aggravation of prices which caused riots in Egypt (Sternberg, 2012). Again, aside climate change and population growth, a major determinant of livelihood welfare (land covers) has also been attributed to government policies (Al-Shammari and Willoughby, 2019) which triggered rising inflation costs, thereby impoverishing the citizenry, particularly, the vulnerable groups. Again, comparative studies for a least developed country like Somalia in the EAF region increase the growing evidence that droughts increase the likelihood of sustained violence for groups dependent on agriculture and individuals/groups marginalized as a result of political exclusion (Brika, 2018; von Uexkull et al., 2016; Raleigh and Kniveton, 2012). In addition to the above arguments, there are international political tensions between the riparian states of the Nile River; thus, Egypt and Ethiopia, as the increase in demand (population) is driving plans upstream (Link et al., 2016).

4.3. West Africa (WAF)

Today, WAF landscapes are the result of cumulative effects of biophysical and human-induced factors, particularly the latter which has spearheaded rapid economic growth and environmental change over the past four to five decades. This has resulting in considerable gains in livelihoods, at the expense of natural ecosystems. WAF is made up of sixteen (16) sovereign states with fifteen of them forming the Economic Community of West African States (ECOWAS). LUCC dynamics in WAF have been primarily driven by population growth and distribution, with growth rates exceeding global averages from the 1950s (Hermann et al., 2020) (Fig. 8). WAF's population in 2015 was 367 million, connoting five

percent of the world's population resided in the region. The region has the highest population growth among other regions across the world, having grown by a factor of five since 1950. The young age structure of the West African population — nearly half of the population is under 15 years old, ensure that population growth will continue both in the short and medium term. Given a medium fertility model, the population of the region is projected to exceed one billion by 2050, with at least one in ten (10) of the world's population, estimated to hail from WAF.

Currently, the population of West Africa is estimated to be 422 million with Nigeria leading with 216. 7 million, which grew from 37.8 million in the 1950s, followed by Ghana with over 30 million. The country with the least population in the sub region, Guinea Bissau has a population of 2 million. The effect of this quintupled population growth in West Africa has exerted considerable pressure on land resources, leading to a continual modification of diverse vegetative covers such as the reduction of woody vegetation in savannas (Brandt et al., 2018), coupled with radical conversion of semi- deciduous forests to savanna and then farm/crop land (Brink and Eva, 2009). The scales of conversion vary for urban and rural areas. Rapid urbanization (Fig. 8) in major cities such as Lagos, Abuja, Abidjan, Accra, Lomé and Freetown have led to a deterioration of several ecosystems, particularly blue, grey and green spaces into built-environment (Adegboyega et al., 2019; Kouadio and Singh, 2020; Puplampu and Boafo, 2021). Rural areas are not left out as land grabbing increases towards agricultural expansion, leading to the transformation of small holdings/woodlands and forests converted into large industrial estates connected to large far-off markets, typical of semi-arid southern Burkina Faso (Ouedraogo et al., 2010; Yira et al., 2016) and northern Ghana (Kleemann et al., 2017). Another driver influencing the spatial patterns of human footprint in West Africa is observed changes in socioeconomic conditions and policies which are underlined by the concept of urban primacy. The concept of urban primacy emphasizes the preeminence of a domineering city in economic, social and political matters in a geographical jurisdiction or the largest city's overwhelming economic, social, demographic and political domination (Meyer, 2019). This concept has largely been associated with developing countries, particularly in West Africa and Sub-Saharan Africa that experienced colonial subjugation (Gunaratna and Gunaratna, 2018; Songsore, 2020).

Studies on West African nations and how the land covers keep changing have gained prominence due to impacts of climate change, LUCC and exponential rates of population growth. Herrmann et al. (2020) analyzing LUCC dynamics for four decades (1975–2013) in West Africa showed that built environment increased from 493,000 km^2 (10 %) in 1975–1121,000 km^2 (23 %) in 2013. In general, LULCC dynamics is an interplay of environmental conditions and anthropogenic activities, influenced by past and current policies, as well as socio-economic constraints (Hermann et al., 2020). Specifically in the case of Nigeria, the enactment of social and economic policies has greatly influenced land use dynamics. The middle belt of Nigeria is mainly under commercial cultivation. In addition, policies on conservation have led to the protection of forest and wildlife reserves (Ariyo and Mortimore, 2011). In Burkina Faso, specifically the northern belt, land cover change (LCC) is explained by topography. Due to their favorable soil water availability and ease of ploughing, agricultural growth has favored east-west oriented fossil dunes. While Burkina Faso's dunes were earlier planted and partially abandoned during the Sahel droughts of the 1970s and 1980s, western Niger's dunes have just recently seen agricultural growth (Rasmussen and Reenberg, 2012).

Other studies by Assenso-Barnieh et al. (2020) in West Africa showed that settlements and croplands expanded at the detriment of natural vegetation from 1975 to 2013 at percentages of 140 % and 107.8 %, respectively. Settlements and croplands were parallel in the quest to feed the growing population and land grabbing by migrants or immigrants. In essence, the scholars argued that land covers such as the LULC classes that dealt with the use of natural resources, such as open-mine fields, towns, plantations, and irrigated and rain-fed agricultural land, grew considerably at the same time. Hotspots of population growth/expansion are seen in the southern West African middle belt and coastal regions, and are particularly noticeable in cities like Lagos, Ibadan, and Abuja in Nigeria; Bobo-Dioulasso, Ougadougou, and the Kadiogo region in Burkina Faso; Kumasi and Accra in Ghana; and many other locations like Abidjan in Cote D'Ivoire; Dakar in Senegal, and Bamako in Mali. In West Africa, the expansion of settlements or population growth remains the core LUCC driver, at the expense of other LULC classes, particularly vegetation (forestland and agricultural lands) in urban and non-urban areas. Studies on LUCC in Ghana have shown a continuous decrease in ecosystem dominated land covers for built-environment, owing to uncontrolled rapid urbanization (Puplampu and Boafo, 2021; Anarfi, Hill and Shiel, 2020), coupled with poor planning and land grabbing in the rural areas (Kleemann et al., 2017).

Spatial results for the present study proved the entire WAF region (refer to supplementary material, Table 3A) had farmlands/shrubs and deserts reducing at a rate of 25.07 % and 64.12 %, respectively. Built-up, grasslands, forests and areas covered by waterbodies increased at a rate of 87.39 %, 20.56 %, 160.67 % and 308.98 %, respectively, over the past four decades. The timing of data acquisition and increasing temperatures in the region might have accounted for the expansion in waterbodies. Just like NAF/SAH region, WAF may similarly be experiencing "*LURC*" considering the gains and shift in area coverage for grasslands, forests and waterbodies, despite the dramatic increase in built environment.

4.3.1. Political unrests, environmental health, resource scarcity and impairment of ecosystem services

The quintupled population growth with continuous grow rates in West Africa does not only change the land covers and their uses but generates a number of implications disproportionately within the sub-region. Paramount amongst them is the trade-off of ecosystems and their services for concrete surfaces in urban environments (Saghir and Santoro, 2018). The centralized approach of development of smart cities results in the concentration of the population and the continuous attraction to the city due to failing farmlands among other socio-economic detriments. The resultant effect is the increasing rate of slums and social injustice or uneven infrastructure development and access to essential resources in the region. In addition, the Sahel region of West Africa has 7 out of the 10 nations that make up the Sahel region of Africa (Mauritania, Senegal, the Gambia, Guinea-Bissau, Mali, Niger and Burkina Faso). The land cover dynamics, increased population and climate change has resulted in droughts and famine. In recent times, expansion in agriculture particularly for countries such as Niger and Mali are low with the area experiencing water deficits/scarcity and receiving rainfall between 12 and 20 in. per year (Potts et al., 2013). Hence, pastoralists and subsistence farmers engage in seasonal migration to cushion their livelihoods. The struggle for limited green cover and water has also resulted in a series of conflicts in the ownership and use of fertile lands and water resources. In addition, climatologists predict an increase in surface temperature by 3–5° C by 2050, and an 8°C amplification by 2100. These undesired changes will significantly affect public health, species diversification and productivity, and ecosystem services. Furthermore, rainfall is projected to decrease with dire consequences on agricultural production from 13 % in Burkina Faso and as high as 50 % for Sudan (Potts et al., 2013). The land use dynamics in the Sahel region will further exacerbate security and governance challenges in the Sahel, coupled with conflicts and the proliferation of Al-Qaeda, Boko Haram and other rebel groups (Potts et al., 2013) which worsen political stability by the day. The FAO classifies four countries in the Sahel- Chad, Eritrea, Niger and Sudan as being in a protracted food crisis (Saghir and Santoro, 2018).

The quintupled growth in population and climate variability issues in West Africa has resulted in power disruptions over three decades.

Obahoundje and Diedhiou (2022) conducted an LULCC study along some selected dams and revealed by 2050, about 20 % of water will be lost due to anthropogenic and climate induced factors. This in turn, will affect the provision of hydropower and the energy sector, citing the Black Volta and Bui dams in terms of hydropower generation. Here, irrigational schemes, real estate/construction and increasing conversion rates of lands into cultivated lands to feed the growing population have devastating implications. Among them are sedimentation and siltation, which are harmful to hydropower plants. In contrast, scenarios on the Kainji dam on the Niger River basin show an increase in rainfall favors the production of hydropower (RCP 4.5 and RCP 8.5) (Obahoundje and Diedhiou, 2022).

4.4. East Africa (EAF)

Based on the categorization presented in the methodology section, the East African regional division has the highest population in Africa. The population of the region was 66 million in 1950, but amplified in 6-fold to 445 million in 2020, according to world population prospects. The region is characterized by water (lakes, rivers and permanent wetlands), evergreen (needleleaf and broadleaf), deciduous (needleleaf and broadleaf), mixed forests, closed shrub, open shrub, woody savannas, savanna, grasslands, crop lands, barren areas and snow/ice (Channan et al., 2014). These land covers have over the decades, been altered due to a variety of competitive needs.

Studies by Bullock et al. (2021) on land use dynamics from 1998 to 2017 depict an increasing pressure for land cover conversions. Their study focused on Ethiopia, Kenya, Uganda, Malawi, Rwanda, Tanzania and Zambia. They discovered that croplands increased by 34.8 %, whereas open grasslands, wooded grassland and open forests suffered a decrease to settlements which gained 43.5 % of the land cover. Kogo et al. (2021) in Western Kenya from 1995 to 2001 reported an initial increase in the built-up areas by 71 %, forest cover by 43 % and farmlands/shrubs by 5 %, whereas the grassland land cover suffered a 47 % reduction as a result of population increase. Subsequently, from 2001 to 2017, the built-up land cover further increased by 225 % and farmlands by 17 %. Other land covers like forests, grassland and areas covered by waterbodies declined by 38 %, 10 % and 11 %, respectively. The resultant effect is the encroachment of sensitive ecosystems, biodiversity loss and alteration in ecological processes which reduces the quality of life and the resilience of the region against climate stressors.

Again, studies by Kweyu et al. (2020) on the Eastern Mau Forest in Kenya show that 40 % of the forest land has been converted into other uses. The Mau catchment provides environmental and economic services. In addition, the region supports energy production (hydro power production which generates 5.3 billion USD annually). The incalculable benefits derived from the Mau catchment area has made the space a contested one which has resulted in political conflicts among some ethnic groups (Kweyu et al., 2020). In Uganda, the Murchison Bay catchment in the northern shoreline of Lake Victoria has undergone tremendous human-induced land cover changes. Studies by Kiggundu et al. (2018) in the area between 1984 and 2015 showed built-up areas increased from 20.58 % to 49.59 %, open water (1.74 %) and a reduction in agricultural areas from 43.88 % to 26.10 %, forests from 23.78 % to 17.49 % and wetlands from 11.76 % to 5.08 %. The continuous transition of natural lands to human-induced lands threatens environmental and water quality within the Murchison Bay in Uganda. Other supporting studies by Kilama Luwa et al. (2021) in Uganda show built-up and agricultural areas keep increasing as forest, wetlands and woodlands decrease at different magnitudes and scales. With population growth on the rise, these transitions threaten ecosystem services, agriculture and the tourism industry.

Overall, the EAF region during the last 40 years according to evidence presented in this study indicates that farmlands/shrubs, grasslands and areas covered by waterbodies declined by 39.73 %, 15.74 % and 79.66 %, respectively. Contrary to local studies conducted previously in Kenya, Uganda, Rwanda and other nations, forests, built environment and deserts increased steadily (1980–2020) at a rate of 19.15 %, 292.35 % and 50.07 %, respectively. The substantial gains in built-up and barren areas show areas covered by waterbodies, grasslands and cultivated lands will be continuously be targeted.

4.5. Central Africa (CAF)

The UN-World Population Prospects estimated the population of central/middle Africa for 2020 to be 179 million. The most populous nation is the Democratic Republic of Congo (DRC) with a population of 89 million in 2020, whilst the least populous nation is Sao Tome and Principe with a population of 219,000 (UN-World Population Prospects, 2019). CAF is predominantly characterized by forests, waterbodies and the built environment. Molinario et al. (2020) posited that between 2000 and 2015, the rainforest of the DRC which traditionally suffered shifting cultivation through slash and burn in later years is experiencing permanent damages through rural complex expansion, new forest clearing and isolated forest perforations which affect forest ecosystems and biodiversity habitats. Since 2000, only 1 % of forest was allotted for mining, plantation, and logging. In 2015, 15 % of the forest was used for large-scale agroindustry and resource extraction which has created a platform for the spring up of ancillary services (i.e., communities for workers) (Molinario et al., 2020). Additionally, their study further revealed a 12 % forest loss within the rural complex expansion, and 9 % of isolated forest perforations within 5 km of mining segments, logging or plantations.

In Gabon, Legualt and Cochrane (2021) identified that the major driver in land cover transitions were not directly as a result of increase in population but as a result of the sale of forests to foreigners (land grabbing/ large-scale land acquisitions). Gabon is a largely forested central African country with still existent intrinsic colonial ties and present-day rights, giving foreigners and transnational companies easy access to its natural resources and fertile lands (Legault and Cochrane, 2021). These have transitioned the natural vegetation into infrastructural developments and the deprivation of nationals in Gabon over the years. In Cameroon, Toh et al. (2018) identified five groups of LULC of thick woody vegetation, light vegetation, savannah, settlements and bare land in the Mount Bambouto Caldera from 1980 to 2016. Three out of the five understudied classes experienced a negligible increase, i.e., cropland (4 %), settlements (0.43 %) and bare land (5.7 %), whilst savannah and forests decreased by 4.4 % and 5.8 %, respectively. Temporal variations for CAF illustrate a steady increase in cultivated lands (+14.37), deserts/bare land (47.16 %), built-up areas (247.94 %) and grasslands (163.38 %). Forests areas as reported in previous local and regional studies in the region declined by 30.63 %. Observed forest degradation may alter species diversity, habitat and ecological harmony of the region as the natural vegetation is being converted to other land use forms which may induce temperature and precipitation changes.

4.6. Southern Africa (SAF)

SAF is predominantly characterized by grasslands, forests, waterbodies, and built-environment. The region has a population of 67 million with South Africa being the most populous. In spite of the Kalahari Desert occupying a large area with several extensions and ecosystems, forest areas in SAF occupies a third of land surface area of nations in this region. Observed changes based on change detection statistics show transition of grasslands, cultivated lands and waterbodies to barren areas, settlements and forests (i.e., natural and artificial), wildlife and parks. In Namibia, studies like Kamwi et al. (2018) reported that forests in both protected and communal areas increased substantially. In the case of cultivated lands/shrubs, there was a reduction in both protected and communal areas. According to Lipper and Benton (2020), nations like Zambia, Madagascar, Mozambique and Angola are the most-endowed in terms of natural forests, and have the largest timber

production capacities, unlike South Africa, Swaziland, Botswana, Lesotho and Namibia where conditions are not so favourable for the aforementioned economic activities. Forests in Zimbabwe and Malawi with high timber were eliminated by extensive agriculture, harvesting of fuelwood, overgrazing and infrastructural development. Early studies (Lipper and Benton, 2020; Hoffman, 2018) have highlighted population growth and distribution, agricultural extensiveness (for instance, expansion of tobacco cultivation, among other food and cash crops), forest fires, market dynamics, overexploitation of fuelwood and forest products as the main drivers of LUCC. Similarly, weak governance systems and pro-poor policies to regulate land use activities, as well as overused pastures/expanded pasture lands which drive desertification and more soil erosion, have been highlighted as indirect factors driving changes in the region (South Africa Department of Water Affairs and Forestry (DWAF), 2000; Saket, 1999a and Saket, 1999b).

Change detection analysis performed for SAF through this study shows farmlands/shrubs, grasslands and areas covered by waterbodies in SAF reduced at a rate of 40.3 %, 44.35 % and 27.99 %, respectively. Contrarily, natural and artificial forests which has recently proven to be of major significance increased at a rate of 28.93 %, whilst deserts have expanded by 66.15 % in area, coupled with built-up also expanding by 44.99 %. These findings align with the reports of early studies conducted by Lipper and Benton (2020), Hoffman (2018), Kamwi et al. (2018) and DWAF.

4.6.1. Loss of ecosystems, conflicts, inequalities, poverty and increased climate vulnerability levels

Perceived outcomes of LULCC could be positive and negative, depending on the direct/indirect benefits or menace, which protrudes from the implication of the said change. Nevertheless, the differences in stakeholder needs vary in terms of the purpose of usage which ranges from conservation, farming, tourism, development and other purposes which have specific values and perspectives. Competitive interests which may evolve may result in conflicts, social injustice/inequalities and so on. Regardless, these activities will be carried out at the expense of the natural environment, which creates a human-environment coupling or cause-and-effect scenarios. The essence of carrying cost-benefit analysis or vital trade-offs in a way that maximizes benefits and sustainability, whilst minimizing undesired consequences and maladaptation, is why studies of this nature are critical to understand land cover change on different scales. Country-based reports (DWAF, 2000) and a surge in recent literature have shown deforestation, soil and forest degradation (Hoffman, 2018), desertification, habitat destruction, increased poverty and vulnerability levels to climate stressors and disturbances, coupled with the intensification and frequency of some climatic events.

4.7. Current trends and future projections of Africa's LULCC

Considering the current trends of immense changes observed across Africa's sub-regions, these predictions (Fig. 11) could occur if strategic and results-oriented measures are not designed to avert or regulate prevailing conditions, driving these undesired and unprecedented changes. The highlighted core and potential drivers (Fig. 10) and trends without regulation defeats the purpose of developing equitable, inclusive, accessible and sustainable regions which align with the principles and goals of spatial sustainability and SDGs 1, 2, 3,11, 13 and 15. Increasing calls to enhance productivity, devise innovative means to avert resource-based conflicts, poverty rates, enhance food security, sustain water resources among other ecological processes and prudent management of lands, water and energy resources from global, regional and local perspectives, substantiate the evidence presented. This in essence, prompts policy-makers, industrial players, international donors and interested parties to circumvent through a multidisciplinary and need-based approach to address LUSD concerns.

Predicted trends for natural vegetation estimate 1.69 % and 2.92 % reduction rates annually for forests and grasslands, respectively, in the next 30 years. Areas covered by waterbodies are expected to shrink by 1.19 %. Carbon sequestration (carbon sink and carbon source), ecosystem functions and end-points (services), and habitat diversity, among other benefits provided by forest resources will be significantly affected. The economic and cultural values gained from forest resources, wildlife, parks and reserves, ecotourist and sacred grove sites could be lost if forests, waterbodies and other essential resources across the length and breadth of this naturally endowed continent are not preserved and sustained. Land use across the continent has changed dramatically in the last few decades and this has had a number of negative consequences, including increased poverty, environmental degradation, and loss of biodiversity. One of the most destructive consequences of land use change in Africa is increased poverty (Hoffman, 2018). By converting agricultural land to housing or industrial sites, land owners can generate short term income. However, these changes also result in decreasing food production, which leads to higher food prices, forcing poorer families deeper into poverty. Additionally, in cases where the land is sold to developers, local communities often move off the land, depriving them of subsistence farming and other income-generating activities.

Environmental degradation is another negative consequence of land use change (LUC) in Africa. LUC cause soil erosion, destroying the ability of the land to sustain agriculture and wildlife. Forests are cut down to make way for roads and other infrastructure, reducing habitat for plants and animals. As such, Africa has seen a dramatic decline in biodiversity with some estimates suggesting that as much as 80 % of wildlife has been wiped out since 1970. In addition, air and water pollution are on the rise in Africa, mainly due to industrial development. For example, in Nigeria and Mozambique, oil spills have resulted in toxic contamination of drinking water, putting society at risk of negative health outcomes. These environmental hazards are of particular concern in Africa, as many countries lack proper regulation and enforcement of environmental standards. Finally, the social implications of LUC encapsulate disrupting livelihoods and traditional lifestyles. It further creates tensions as individuals and groups compete for resource accessibility, which results in conflicts.

4.8. Enhancing land-use governance and sustainability across Africa through the "4R value strategy"

Increasingly, the notion and discourse toward LULC and the environment is shifting from being viewed solely as bottlenecks, toward opportunities and solutions. From a policy perspective, production and exchange of evidence-based innovation means adhering to "transformative governance, equity and justice", "developing sense of empathy faced by the marginalized", "empowering scientists to engage the society on how information can be shared and used for the benefits of relevant players" and moving beyond "training of mere specialists to critical thinkers, in the face of uncertainties and converging crises which no one has the recipe to address in the short-term." According to Chaffin et al. (2016), "transformative governance is an initiative embedded in environmental governance that has the capacity to respond to, manage, and trigger regime shifts in coupled socio-ecological systems at different levels." They further opined that the concept is ingrained in ecological theories, social theories of change, innovation and technological transformation, targeted to digest a web and connectivity of complex systems. Transformative governance and land use are essential concepts that harness the transformative power of land development, multifunctional and sustainable landscapes. These approaches to governance and land use planning move beyond conventional strategies, as it encourages a broad, cooperative partnership between governments, sectoral players, and the local communities.

Unforeseen events and impacts yet to come depend on the actions we take today; hence, calls for innovative approaches that respond to

regime shifts triggered by LULCC, climate change, social inequalities and so on. Calls for approaches that focus on identifying system drivers and indicators, co-integration and management among key actors at all levels have yielded effective ambivalence in addressing issues that engulf the sustainability and governance of LUS. Driving forces presented in Table 9, ranging from low to very high impact factors, have militated Africa's sustainable use of land and other natural resources. Attempts to identify and map clear institutional roles or responsibilities in the execution of required tasks have been thwarted by several bottlenecks in various policies and legislative instruments. Fig. 12 proposes four key tactics in the effective administration of land-use and climate systems.

The first key tactic (Fig. 12) to enhance land-use governance in Africa is to make PPPPs that engulf land-use development and sustainability "*real.*" Here, relevant stakeholders need to consider what is proactive, comprehensive, workable and acceptable in addressing technological, socio-cultural, environmental, economic and political drivers of land use cover change across the sub-regions in Africa. Strategies must be tailored with all inputs from the relevant or interested parties, devoid of imposition (i.e., actors do not solely prioritize economic and political benefits, market-based values or selective judgements on whose values/opinions count in decisions). Addressing questions like:

i. What are the core issues that ought to be prioritized?
ii. How can we develop a balanced approach, and what is the next line of action?
iii. In what way can we do it best — reactionary or anticipatory means?
iv. How can we be actionable? Developing new mindsets or social systems lie in adapting this strategy.

These could serve as a reference point for further action among stakeholders through a shared or common goal (desire). Despite adaptation efforts, impacts of land degradation and climate change are widespread with poverty-traps or tracks; hence, need for a transformative approach that brings all factors to bear.

Consequent to the initial strategy, facilitating the "*relevance*" of prioritising land-use concerns and studies in the current age of anthropocene remain critical in our quest to achieve the 17 goals set out by the United Nations. Virtually every activity takes place on land, making it complex, interdisciplinary, and a critical element that influences the earth's observational and atmospheric processes. Perceptions of land degradation and restoration are socially contested and constructed via diverse means. An aggregate of activities at different levels, is what drives change globally. This, therefore, provides useful parameters that could be deployed at the local level to address issues that influence the sustainable use of land. Development, according to the Neo-Marxist theory, is not a "*linear evolutionary*" process; hence, practical solutions must be tailored to suit the context or settings of some geographical areas, considering the interplay of factors that create irregularities and distinction of regions. Rational interventions to address land and climate issues might fail or result in maladaptation or unintended consequences. Therefore, global conventions or protocols must be studied carefully, and designed to identify, prioritise, highlight and address critical issues

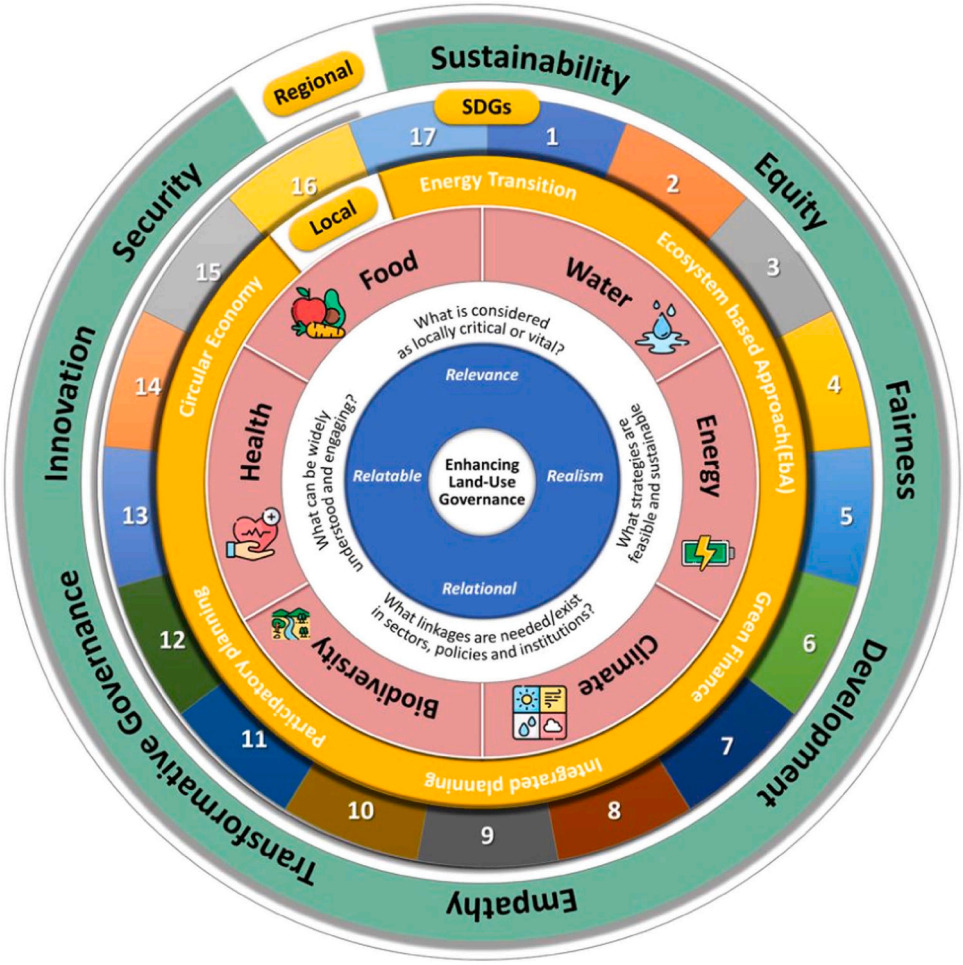

Fig. 12. Need-based '4R value strategy' for land-use governance and sustainability. Source: Authors' construct.

of utmost concern. Again, the relevance of a collective approach can detect and ascertain the contribution of public and private agencies/organizations (i.e., through multistakeholder partnerships – SDG 17) towards the achievement of other SDGs. The "*relevance*" strategy could enhance theory of change, based on the rural-urban divide, shared motivation and working together on proposed future pathways among relevant parties. Delays in decision making and power crisis in planning and management of natural resources could be minimised when land-use governance strategies are made relevant in all fronts. For instance, adoptability of "*cost-benefit*" and "*cost-effective*" analyses based on comparisons (i.e., pros and cons) of prioritising and boycotting initiatives, respectively, could be useful in decision-making.

The third strategy is to make land-use governance strategies "*relatable.*" Fundamental and unprecedented drift in LUS can be observed across the given sub-regions in Africa (Fig. 7). Factors driving these remarkable changes are induced by anthropogenic factors, which aggravate the need to make these strategies— sustainable, relatable and easy to comprehend. Effective environmental communication via social media and informal approaches, ethics of science, engagements and empowerment of young scientists across the globe to add their voices to the growing debates on environmental problems and state-of-the-art solutions that synthesize SDGs for easy understanding among the populace through mass sensitization, educational campaigns and outreach programs could shape people's lifestyle and attitudes towards the environment. This could simultaneously foster principled engagement and involvement, which align with United Nations Local Agenda 21 principles. The third strategy culminates the first and second strategies that demonstrate progress and monitoring of outcomes, bearing how all stakeholders or institutions (inter-and-intra) that influence or are impacted, grasp the objective of working collectively towards a common goal.

The fourth strategy dwells on establishing linkages and building coalitions; thus, making land-use governance strategies "*relational.*" This strategy synergises the application and theoretical values of scientific knowledge, which works across different fields. It encompasses the other three strategies that create avenues for sustainable utilisation of lands. It draws on the tenets of empathy, equity and equality in accessing basic services and alleviation of poverty. Bai et al. (2017) moved advocacy for smart cities have driven the exclusion of traditional nature-based inhabitants in most forests, fishing/lakes and woodlots, grazing/rangeland regions under Public-Private-Partnership programs, thereby heightening concerns for social injustice.

In summary, the proposed *"4R* value strategy" does not completely present a "perfect" land-use governance institutionalisation or decision-making paradigm. Each strategy presents a unique opportunity that challenges the conventional authoritarian approach in enhancing land-use governance across Africa. The *4R value strategy* will be relevant to key proponents confronted by the identified drivers of LULCC and climate change at multiple scales. Making land-use governance strategies *relational, relevant, real and relatable* can facilitate strategic, tactical, timely and sustainable means of ensuring the optimal use of land and other natural resources. These tailored measures can facilitate the realization of the United Nations' Agenda 2030 targets, coupled with quantifying and monitoring progress when advocating improved quality of life, alternative futures, justice and equality across all levels.

5. Conclusion

LULCC has been, and will continue to be, one of the critical drivers of global environmental change. The fear of the unknown and concerns over sustainable use of land reverberates, and echoes need-based solutions through policy and scientific research processes alike. Based on evidence presented, our study draws the following conclusions. Findings demonstrate that Africa is currently experiencing rapid changes in its LULC, particularly in built-up (+216.52 %) and areas covered by waterbodies (+84.44 %). Surprisingly, "*Land Use and Recover Change*" (i.e., regrowth in forests (+2.67 %)) can be observed in NAF and WAF regions. Empirical results and a plethora of studies reveal a subtle decline in deserts (-16.62 %) and cultivated lands (-12.88 %). The increasingly significant changes over the past 40 years move beyond identifying population growth and distribution, and urbanization as the sole drivers of change. Other institutional and socio-economic contributory factors include expansion in agricultural activities, weak governance systems and technological advancements. Similarly, biophysical factors, mainly induced by climate change have partly influenced land-use transitions.

Predicted trends (2020–2050) for natural vegetation estimate 1.69 % and 2.92 % annual reduction rates for forests and grasslands, respectively. The proposed construct '*4R value strategy*' presents an innovative path that unifies actions, address resource use-related conflicts, core and potential drivers identified. Since attaining reliable and valid data for Africa remain an arduous challenge, land use maps generated in this study will support land-use governance, as a means to avert potential risks associated with future changes in growth patterns, natural disasters, resource scarcity and related conflicts. The proposed construct serves as a great experimenting tool towards the evaluation of SDGs 11, 13 and 15.

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CRediT authorship contribution statement

Isaac Sarfo: Conceptualization, Design, Data curation, Methodology, Formal analysis, Validation, Visualization, Writing – Original and final drafts, Review and Editing. **Jiajun Qiao:** Supervision, Project Administration, Provision of Resources, Validation, Review and Approval of Final Draft. **Emmanuel Yeboah:** Data curation, Methodology, Statistical analysis, Validation. **Dzifa Adimle Puplampu:** Formal Analysis, Review and Editing. **Clement Kwang:** Methodology, Investigation, Validation, review and editing. **Iris Ekua Mensimah Fynn:** Formal analysis, Validation, Review and Editing. **Michael Batame:** Data curation, Investigation, Methodology, Validation and Formal analysis. **Emmanuella Aboagye Appea:** Data curation, Methodology and Formal analysis. **Daniel Fiifi Tawia Hagan:** Investigation, Validation, Review and Editing. **Rosemary Achentisa Ayelazuno:** Data curation, Methodology, Formal analysis, Validation. **Valentina Boamah:** Validation, Review and Editing. **Benedicta Akua Sarfo:** Validation, Review and Editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

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Data Availability

Data will be made available on request.

Code Availability

Software and links to all database have been provided in the methodology section

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.landusepol.2024.107261.

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